# Effect of oil palm sustainability certification on deforestation and fire in Indonesia

Kimberly M. Carlson[a,b,1,2], Robert Heilmayr[a,c,1], Holly K. Gibbs[d,e,f], Praveen Noojipady[g,h,i], David N. Burns[g], Douglas C. Morton[h], Nathalie F. Walker[g], Gary D. Paoli[j], and Claire Kremen[k]

[a]Department of Natural Resources and Environmental Management, University of Hawaii, Honolulu, HI 96822; [b]Institute on the Environment, University of Minnesota, Saint Paul, MN 55108; [c]Environmental Studies Program, University of California, Santa Barbara, CA 93106; [d]Department of Geography, University of Wisconsin, Madison, WI 53726; [e]The Nelson Institute for Environmental Studies, University of Wisconsin, Madison, WI 53726; [f]Department of Geography, University of Wisconsin, Madison, WI 53706; [g]National Wildlife Federation, National Advocacy Center, Washington, DC 20005; [h]Biospheric Sciences Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD 20771; [i]Earth System Science Interdisciplinary Center, University of Maryland, College Park, MD 20742; [j]Daemeter, Eureka, CA 95501; and [k]Department of Environmental Sciences, Policy and Management, University of California, Berkeley, CA 94720

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**Many major corporations and countries have made commitments to purchase or produce only "sustainable" palm oil, a commodity responsible for substantial tropical forest loss. Sustainability certification is the tool most used to fulfill these procurement policies, and around 20% of global palm oil production was certified by the Roundtable on Sustainable Palm Oil (RSPO) in 2017. However, the effect of certification on deforestation in oil palm plantations remains unclear. Here, we use a comprehensive dataset of RSPO-certified and noncertified oil palm plantations (~188,000 km$^2$) in Indonesia, the leading producer of palm oil, as well as annual remotely sensed metrics of tree cover loss and fire occurrence, to evaluate the impact of certification on deforestation and fire from 2001 to 2015. While forest loss and fire continued after RSPO certification, certified palm oil was associated with reduced deforestation. Certification lowered deforestation by 33% from a counterfactual of 9.8 to 6.6% y$^{-1}$. Nevertheless, most plantations contained little residual forest when they received certification. As a result, by 2015, certified areas held less than 1% of forests remaining within Indonesian oil palm plantations. Moreover, certification had no causal impact on forest loss in peatlands or active fire detection rates. Broader adoption of certification in forested regions, strict requirements to avoid all peat, and routine monitoring of clearly defined forest cover loss in certified and RSPO member-held plantations appear necessary if the RSPO is to yield conservation and climate benefits from reductions in tropical deforestation.**

Roundtable on Sustainable Palm Oil | peatland | quasi-experimental methods | governance | tropical commodity

Global demand for agricultural and timber commodities has emerged as the primary driver of tropical deforestation (1). Reduction of such commodity-driven deforestation supports climate change mitigation (2, 3), biodiversity preservation (4, 5), air quality improvements and associated human health outcomes (6), water quality protection (7), and forest-based livelihoods (8). While state-sponsored and bilateral programs to address forest loss face several criticisms and barriers (9), export-oriented supply chains have characteristics that offer novel possibilities for conservation interventions. Commodity supply chains are often concentrated in the hands of just a few "lead" firms that exert substantial influence over their suppliers (10). Recognizing this opportunity, civil society organizations have pressured commodity and consumer goods companies to alter their sourcing and production practices to eliminate deforestation.

As a result of these campaigns, by 2017, almost 400 companies in tropical oil palm, soy, timber, and cattle sectors had adopted public commitments to more "sustainable" product sourcing (11). These commitments are lauded by civil society as proof that market-driven approaches to conservation can benefit forests (3, 12). Indeed, research in South American soy, beef, and forestry sectors indicates that commitments affect actor behavior within target supply chains (13) and may reduce deforestation from commodity production (14–16). Over 55% of these sustainability commitments reference certification, systems that use third-party audits to ensure that producers follow a set of social and environmental practices to realize their pledges (11). A widely certified agricultural commodity is palm oil (17), which is produced mainly in Southeast Asia (18). Companies that produce, trade, and sell palm oil have adopted certification to signal that their products are sustainable, and that they have taken steps to minimize the negative environmental and social impacts linked to palm oil production (2, 6, 19–22).

About 20% of global 2015 palm oil production was certified by the Roundtable on Sustainable Palm Oil (RSPO) (17). Certified oil palm growers agree to comply with the RSPO Principles and Criteria (P&C) standard, which does not require zero deforestation, but limits the land covers that may be developed for oil palm. Specifically, new plantings since November 2005 may not clear primary forest or high conservation value (HCV) areas (23). Certification requires riparian buffer protection, whereas noncertified plantations sometimes clear to the edge of water bodies (24). The P&C mandate avoidance of steep slopes and fragile soils, and ban extensive planting (>100 ha) on peatlands, which have been

## Significance

**Demand for agricultural commodities is the leading driver of tropical deforestation. Many corporations have pledged to eliminate forest loss from their supply chains by purchasing only certified "sustainable" products. To evaluate whether certification fulfills such pledges, we applied statistical analyses to satellite-based estimates of tree cover loss to infer the causal impact of a third-party certification system on deforestation and fire within Indonesian oil palm plantations. We found that certification significantly reduced deforestation, but not fire or peatland clearance, among participating plantations. Moreover, certification was mostly adopted in older plantations that contained little remaining forest. Broader adoption by oil palm growers is likely needed for certification to have a large impact on total forest area lost to oil palm expansion.**

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[1]K.M.C. and R.H. contributed equally to this work.

[2]To whom correspondence should be addressed. Email: kimcarlson@gmail.com.

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de facto available for development in Southeast Asia (22). In regions with strict environmental regulations but weak enforcement (17), the RSPO's requirements for full legal compliance could restrict which lands are developed for palm. All certified developments must gain free, prior, and informed consent from local communities, which might reduce conversion of community-held lands, including agroforests (25). Finally, a requirement to avoid fire use (26) may reduce accidental forest loss in certified plantations (27).

However, the P&C allow conversion of logged and degraded forest outside riparian and HCV areas, and do not fully prohibit peatland development (28). This lack of stringency resulted from the compromise needed to bridge divergent corporate and civil society interest groups during the 2013 P&C negotiation (29). Certified growers are not required to publish HCV area boundaries, which prevents remote monitoring of HCV vegetation change. Moreover, companies planning to seek certification plausibly faced perverse incentives to clear forests before implementation of the RSPO's 2010 New Planting Procedure (NPP), which levies sanctions on growers that undertake development without an HCV assessment. Due to these issues, and nongovernmental organization reports questioning the credibility of third-party auditors (30), the RSPO has been criticized by civil society for "greenwashing" palm oil grown in recently cleared forests and drained peatlands (31).

Despite such controversy, the effects of RSPO certification on forests, including primary, peatland, and other forests protected by the P&C, remain largely unmeasured (32). Instead, initial research has focused on fire in Indonesia using recently available plantation datasets. An assessment of 2012–2015 fire incidence reported similar fire rates in RSPO member-held and noncertified plantations when all soil types and precipitation regimes were considered (26). Exploring a larger plantation sample, Noojipady et al. (27) reported fewer fire-associated deforestation events in certified plantations from 2009 to 2014. While such research informs the degree to which certified products are associated with fire, these comparisons were unable to estimate the causal effect of certification on environmental outcomes because they evaluated differences over broad time periods, rather than comparing pre- and postcertification trends (33, 34). Since certification is voluntary, certified producers may have sought certification because their practices were already near compliance with the standard (34), and thus the cause of any differences may be unrelated to certification. Quasiexperimental counterfactual analyses aim to address this problem by determining likely outcomes in the absence of certification. Comparing the counterfactual with reality enables accurate quantification of certification's benefits above and beyond noncertified production (34).

Here, we evaluated the causal impact of RSPO certification on deforestation, peatland development, and fire activity in Indonesia from 2001 to 2015. In 2014, Indonesia accounted for 40% of global oil palm harvested area (18) and 44% of RSPO-certified area (17). We constructed a comprehensive dataset of certified and noncertified oil palm plantations (35, 36)* (Fig. 1). Within these plantations, we used annual satellite data products to track the occurrence of fire (37) and loss of primary forest (38), peatland forest, and forest areas with >90% tree canopy cover (excluding tree plantations) (39, 40) (Fig. S1). Propensity score matching controlled for significant precertification differences between certified and noncertified plantations (Table S1). We applied panel models to compare certified and noncertified plantations from 2000 to 2015. Since data delineating HCV boundaries, primary forests, riparian buffers, and other lands targeted for protection under the RSPO standard were unavailable, and the causes of observed burning events were unknown, our analysis did not evaluate compliance with the RSPO P&C. For instance, our remotely sensed primary forest dataset (38) is not necessarily equivalent to primary forest areas identified during RSPO audits. Instead, our research provides credible evidence for the impact of RSPO certification on forest protection and fire reduction.

*Sawit Watch (2013) Palm oil concessions in Indonesia.

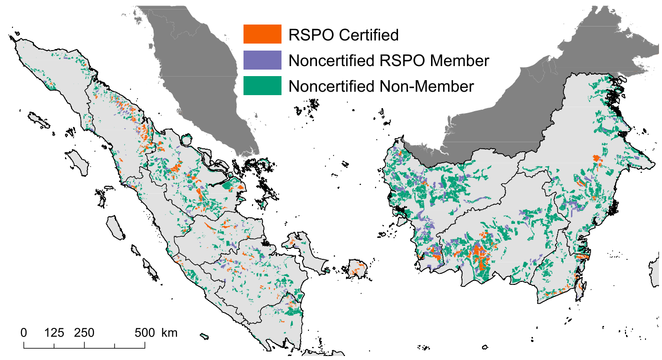


**Fig. 1.** RSPO-certified and noncertified oil palm plantations. Across Indonesia (light gray), plantation area totaled 187,567 km$^2$ ($n$ = 2,331 plantations). About 53% of the total certified area was in Sumatra (including the Bangka Belitung Islands, *Left*), and 47% was in Kalimantan (Indonesian Borneo, *Right*).

## Results

**Adoption of Certification.** The first RSPO certificate in Indonesia was issued in 2009. By January 2017, 7.0% of plantations in our database were associated with mills that had issued a letter of intent (LOI) to certify with the RSPO ("certified," 17,212 km$^2$, $n$ = 163), which occurred 0.84 ± 0.61 y (mean ± SD) before gaining certification. Another 9.8% of plantations were held by RSPO members (22,679 km$^2$, $n$ = 228), and the remainder belonged to nonmembers (147,676 km$^2$, $n$ = 1,940). The RSPO does not require full certification of all plantation supply bases within a specific time frame. Instead, members provide time-bound plans for full certification and report their progress annually. Once certified, plantations are expected to maintain full compliance with the P&C. We identified 68 RSPO members with plantation holdings in Indonesia. Our database contained 59 of these member companies, with 6.6 ± 6.8 plantations per member. Many RSPO members have certified some of their plantations, while others have yet to certify a single plantation. Only 34 RSPO members in our database held any certified plantations (4.8 ± 5.4 certified plantations per member).

**Selection Bias in Patterns of Certification.** We observed substantial selection bias in certification patterns. The mean initial planting date for certified plantations in Indonesia was 1993. In contrast, >50% of 2014 Indonesian oil palm harvested area was developed after 2003 (18) (Fig. 2*A*). Only 8.3% of certified plantations initiated planting from 2005 to 2008, and no plantation with post-2008 initial development was certified by March of 2017. Because of these differences, certified plantations began the study period with less forest and more oil palm than noncertified plantations (Fig. 2 and Table S1). In 2000, certified plantations collectively contained 12% forest (1,988 km$^2$), 4.0% primary forest (691 km$^2$), and 40% planted oil palm (6,939 km$^2$), while noncertified plantations had 36% forest (61,383 km$^2$), 24% primary forest (41,141 km$^2$), and 6.5% oil palm (11,010 km$^2$). Sumatra's certified plantations contained less forest in 2000 (5.3% of plantation area in forest) than those in Kalimantan (19%). We observed less bias in the colocation of certified plantations and peatlands. About 13% of certified and 19% of noncertified plantation area occupied peatlands.

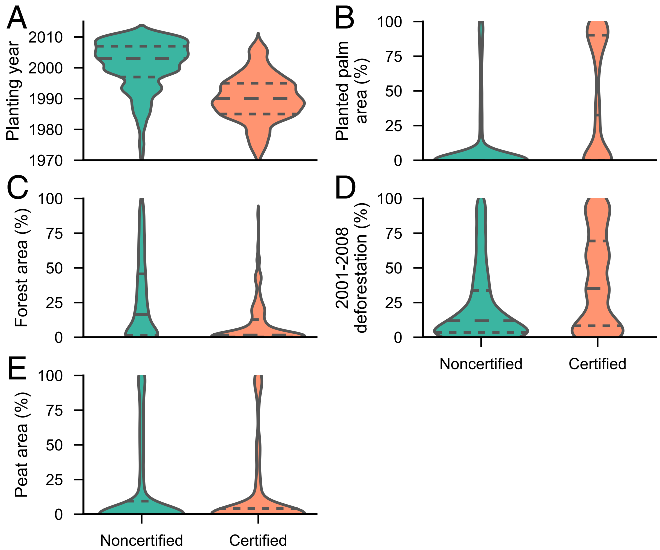


Fig. 2. Differences between RSPO-certified and noncertified oil palm plantations in Indonesia. Compared with noncertified plantations, certified plantations were older (*A*, planting year), with more planted oil palm (*B*, percentage of plantation in oil palm in 2000) and less forest (*C*, percentage of plantation in forest in 2000). (*D*) Certified plantations lost more year 2000 forests by 2008 than noncertified areas (percentage of year 2000 forests lost, 2001–2008). (*E*) Peatland proportion (percentage of plantation in peatland) was similar in certified and noncertified plantations. Plots depict kernel density estimates of the values for all plantations in the category, including median (center lines) and interquartile range (dashed lines).

**Deforestation and Fire Embodied in Oil Palm Production.** The aggregate annual 2000–2015 deforestation rate across all plantations was 3.3% $y^{-1}$. Deforestation increased from 0.74% $y^{-1}$ in 2001 to a maximum of 6.5% $y^{-1}$ in 2012 before falling to 4.0% $y^{-1}$ in 2015 (Fig. 3*A*), with similar temporal dynamics for peat and primary deforestation (Fig. S2). Higher deforestation rates were correlated with smaller remaining forest areas. Thus, while Kalimantan plantations had a lower aggregate deforestation rate (4.1% $y^{-1}$) than Sumatra plantations (7.5% $y^{-1}$; Fig. S3), total 2000–2015 forest loss in plantations was greater in Kalimantan (18,439 $km^2$) than Sumatra (5,451 $km^2$). Active fire rates from 2002 to 2015 averaged 0.078 fire detections per square kilometer per year. Fire rates in all plantations were lower from 2007 to 2013 compared with the 2002–2006 and 2014–2015 periods (Fig. 3*B*).

Most deforestation and fire in certified plantations occurred before certification. Mean deforestation rates for annual cohorts of certified plantations peaked about 5 y before LOI publication (Fig. 3 and Fig. S4). Like Noojipady et al. (27), we found high active fire detection rates in certified plantations from 2002 to 2006 and relatively lower rates since that time (Fig. 3). Deforestation and fires continued after certification, and are therefore associated with or "embodied" within certified oil palm products (1). A total of 91 $km^2$ of forest loss (including 24 $km^2$ of peat and 23 $km^2$ of primary forest loss) and 1,810 active fires were detected in certified plantations after initiation of the certification process. By 2015, certified plantations contained just 330 $km^2$ (0.86%) of all remaining 38,286 $km^2$ of forest, and 80 $km^2$ (0.30%) of remaining primary forest (27,254 $km^2$), in Indonesian oil palm plantations. Audit reports specify that ≥650 $km^2$ of certified plantations are conservation or HCV lands. The lack of HCV boundaries prevented assessments of whether forests remaining in certified plantations occurred in HCV areas.

**RSPO Certification's Impact on Forests and Fire.** Certification reduced deforestation rates by 33%, from a counterfactual mean of 9.8 to 6.6% $y^{-1}$ ($P = 0.028$; Fig. 3*C* and Table S2). Relative to forest remaining at LOI, simulations indicate that certification resulted in 21 ± 2.8 $km^2$ of "avoided" deforestation through 2015. This is equivalent to 23% of the postcertification deforestation, or 6.4% of remaining 2015 forest area, within matched certified plantations. Findings were significant across most alternate matching methods and models, including matching within administrative district and RSPO member, and the model did not violate tests of parallel trends (Tables S2–S4). Only when we applied lower canopy cover thresholds of 30% or 60% to define "forest" did we detect no significant effect of certification on deforestation (Table S4). Deforestation reductions were driven mainly by dynamics within Kalimantan plantations, where certification reduced deforestation by 40% ($P < 0.001$). In Sumatra, certification was associated with reduced forest loss, but this effect was not significant ($P = 0.57$; Fig. S3 and Table S4).

Certification had a large but less significant effect on primary forests, where it reduced deforestation by 36% ($P = 0.053$; Fig. S2 and Table S2). Our main statistical model yielded no evidence for a causal effect of certification on peatland forest clearing ($P = 0.50$; Fig. S2 and Table S2). Although the main model indicated that certification may have reduced fire rates ($P = 0.081$; Fig. 3*D* and Table S2), temporal trends in fire rates for certified and noncertified plantations were not similar before certification, a violation of the parallel trends assumption (Tables S3 and S5). This led us to reject the hypothesis that certification had a causal effect on fire rates.

Despite reductions in deforestation after certification, certified plantations lost 84% (1,657 $km^2$) of their year 2000 forest cover by 2015, while noncertified plantations in the filtered

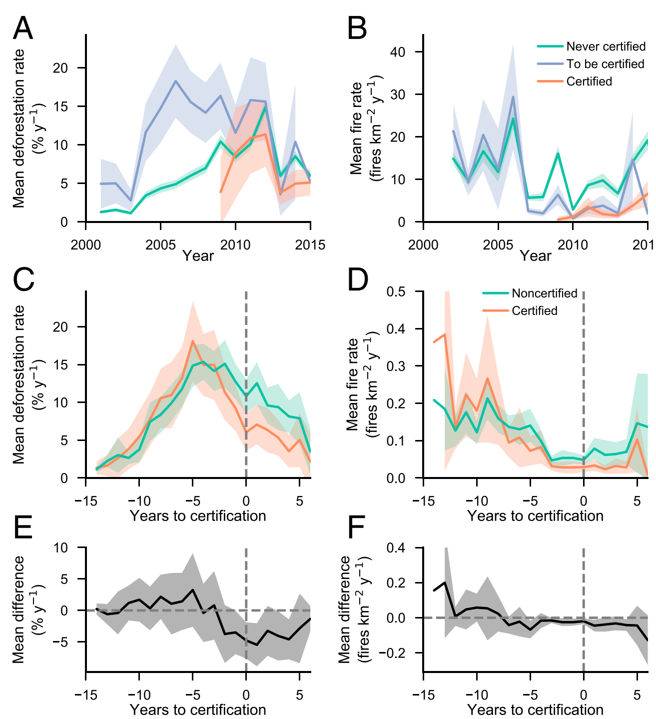


Fig. 3. Temporal trends in deforestation and fire within Indonesian oil palm plantations. (*A* and *B*) Unmatched rates of deforestation and fire in RSPO-certified, to be certified, and noncertified plantations. (*C* and *D*) Matched rates of deforestation and fire in RSPO-certified and noncertified plantations as a function of years to certification for the certified sample. (*E* and *F*) Mean difference in deforestation or fire between RSPO-certified and noncertified plantations. Rates are per plantation, averaged across all plantations in the group. Matched figures in *C*–*F* represent within-island matching through 2008. Noncertified statistics in matched figures in *C*–*F* were calculated using synthetic control plantations. The vertical dashed line represents certification initiation, and shading indicates 95% confidence intervals.

unmatched plantation sample (*Matching and Subsetting*) lost only 38% (23,428 $km^2$). This effect was due to higher precertification deforestation rates in certified plantations compared with noncertified counterparts. Around 97% of deforestation in certified plantations occurred before LOI submission. Our main models treated this precertification difference as selection bias, and sought to minimize this bias by matching deforestation rates through 2008. This difference could instead be evidence of anticipatory behavior, in which companies seeking certification shifted deforestation to the precertification period. We explored potential for such anticipation through models that matched through 2003, the year before RSPO formation (Tables S5 and S6). These models indicated a 36% deforestation increase 4–8 y before certification ($P = 0.02$) and a 20% decrease in postcertification deforestation ($P = 0.29$; Fig. 4 and Table S6).

## Discussion

**Certification's Impact on Forests.** Our models suggest that RSPO certification reduced deforestation in high tree cover areas and primary forests compared with similar noncertified plantations. As a result, certified plantations retained more forest relative to the amount of forest present when the LOI was issued. Deforestation reductions were particularly large within primary forests, areas targeted for protection by the P&C. Previous work indicates that such forests provide several important ecosystem services, including retention of biodiversity and carbon storage (4, 41). Our finding that certification leads to 33% reduced deforestation is similar to research in the logging, timber plantation, and coffee sectors that found significant reductions in deforestation of 2–25% due to third-party certification (16, 42). Our result contrasts with work that found no effect of coffee or logging certification on forest loss (43–46). Thus, RSPO certification appears to be at least as effective as similar certification systems at reducing deforestation.

Nevertheless, certified plantations incurred some deforestation, including in primary and peatland forests. After certification, mean deforestation rates remained high at 6.6% $y^{-1}$, and plantations lost 91 $km^2$ of forest. Since RSPO members were bound by HCV and primary forest conversion rules from November 2005 onward, this observed deforestation was either allowable under the P&C or occurred in violation of the P&C and should be compensated via the RSPO's Remediation and Compensation Procedure (47). Moreover, certification had no impact on deforestation in lower tree cover areas. While these areas may be considered forest by the government of Indonesia (38, 48), they could have been logged, burned, or part of agroforestry or shifting agricultural systems (49), and were thus less likely to be considered HCV or primary forest by auditors. While certification had no significant impact on deforestation in peatlands, small sample sizes in peatland models limited our power to detect any such effects (Table S2).

The significant impact of certification on deforestation in Kalimantan, but not Sumatra, suggests that the context in which certification occurs matters. Upon LOI publication, Sumatra plantations contained just 1.4% forest versus 3.2% in Kalimantan plantations. Potential forest protection through certification was thus lower in Sumatra, and any effect of certification may have been undetectable due to inaccuracies in our geospatial datasets. This result supports recommendations to target supply chain interventions to high-risk locations, rather than regions where producers can easily meet standards (17).

Our incorporation of time-varying effects advanced previous approaches used to evaluate interactions between certification and deforestation (16, 42–46), and allowed us to examine behaviors that tend to occur before and after certification. Temporal trends in treatment effects suggested that deforestation in certified plantations was higher before certification (Fig. 4 and Table S5). This dynamic could indicate temporally varying differences between certified and noncertified areas. Specifically, in some cases, LOI submission may signal a newly operational mill and completion of plantation development. Models that matched through 2003 did not control for differing plantation development trajectories from 2004 to certification. Alternatively, we speculate that companies seeking certification may have increased their precertification forest clearing with the understanding that such activity would be restricted after the initiation of the certification process. Whether strategically motivated or not, over time, elevated precertification deforestation may be offset by the postcertification decrease in deforestation (Fig. 4 and Tables S5 and S6). If RSPO-certified growers protect remaining forests while deforestation continues in noncertified areas, the relative benefits of certification for forests may increase with time since certification.

**Fire and the RSPO.** Like Noojipady et al. (27), we found that RSPO-certified plantations had substantially lower fire rates than noncertified plantations in the post-2009 period. However, this difference in fire incidence rates developed multiple years before certification, invalidating causal claims that certification reduced fire occurrence (Fig. 3*C*, Fig. S4, and Tables S1 and S5). Although we matched plantations with similar fire histories and controlled for interannual variations in temperature and precipitation (50), we did not assess certification's effects specifically during wet years with lower fire risk, when previous work suggests that certification is associated with reduced fire rates (26).

**Potential Drivers of Nonforest Bias.** Consistent with incentive structures facing oil palm producers, we found strong bias toward certification of plantations with little remaining forest. Some drivers of this bias are unlikely to affect the degree of forest protection conferred by the RSPO. For instance, RSPO rules oblige plantations to have an operational mill to certify, which means that they (or their suppliers) must develop enough plantation area to support the mill before certification. While principle 7 of the P&C is designed to ensure that HCV areas and primary forests remain unconverted, other forest types (i.e., areas with high tree cover, such as agroforests, that are potentially allowable for conversion under the P&C) are likely to be cleared before certification. Moreover, in our evaluation of time-bound plans, RSPO member companies in Indonesia with uncertified supply bases certified an average of 0.87 plantations per year. Companies typically proceeded in chronological order, such that the oldest plantations, which are least likely to contain forest, were certified first. This bias may diminish as RSPO members certify all their plantations.

Other sources of bias could restrict the ability of RSPO certification to significantly affect industry-wide deforestation rates. Indonesian regulations require that companies use 100% of their

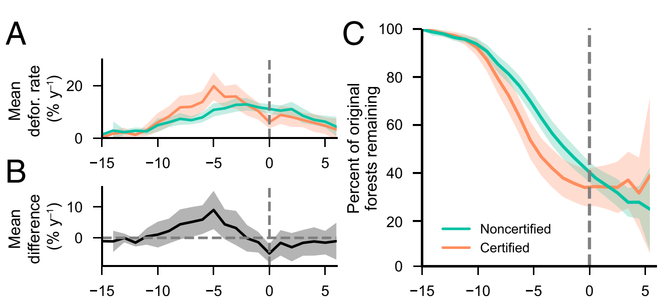


**Fig. 4.** Temporal trends in deforestation (defor.) and remaining forest in RSPO-certified and noncertified oil palm plantations in Indonesia matched through 2003. The deforestation rate (*A*), mean difference in deforestation rate between RSPO-certified and noncertified matched samples (*B*), and percentage of remaining forests relative to year 2000 (*C*) were derived from samples matched through 2003. Noncertified statistics were calculated using synthetic control plantations. The vertical dashed line represents certification initiation, and shading indicates 95% confidence intervals.

leased arable land area, including forested lands, for plantation activities (51). Thus, RSPO members in Indonesia may avoid acquiring high forest cover areas, or excise forests from land leases, to avoid the conflict between legality and sustainability. Second, recently developed and undeveloped leases are subject to the Remediation and Compensation Procedure and/or the NPP. Certifying these areas likely incurs high audit and compliance costs (52), which could dissuade companies that hold leases with extensive forests from joining the RSPO. Finally, pressure by civil society on the palm oil sector seeks to eliminate deforestation from corporate supply chains (12). Given the cost of managing forested landscapes (53), and the negative impact on reputational risk if forest within plantations is lost (3), companies with sustainable supply chain goals may prefer to develop nonforest areas or excise forested areas from their land banks rather than protect HCV areas. Such selective plantation establishment is unlikely to influence currently certified plantations, since 91% initiated development before RSPO founding in 2004.

**Contribution to Transparency.** While the plantation dataset presented here is the most comprehensive accounting of oil palm concessions currently available for Indonesia, the noncertified data contain omissions, commission errors, and incomplete identification of RSPO member-held concessions. Inaccuracies result from Indonesia's complex land enclosure processes, lack of a complete and centralized government concession database, and a culture of secrecy surrounding corporate land transactions (54). Our matching procedure likely reduced the influence of such inaccuracies on analytical outcomes. However, if plantations were omitted nonrandomly, or if RSPO member-held plantations are sold and never gain certification, this would bias our results. In contrast, our certified plantation database included 81% of all Indonesian plantations certified by January 2017. By publishing audit reports with plantation boundaries, the RSPO demands more transparency from growers than is the norm. Accurate plantation boundaries provide the basis for public scrutiny, and the possibility to assess certification's impacts. We still lack data on lands, like HCV areas, "off-limits" for development. Such data would support ongoing monitoring, verification, and enforcement of the P&C as they relate to land cover.

## Conclusion

RSPO certification provides an indicator to guide customers toward palm oil purchases associated with lower recent loss of high tree cover and primary forests, as well as fire incidence. We found that lower deforestation embodied in certified products resulted largely from certification that skewed toward plantations with few remaining forests. The significant impact of certification on deforestation indicates that higher levels of certification could generate greater forest protection.

The RSPO is under pressure to meet recent pledges by corporations and oil palm-importing countries to source only deforestation, and peat-free, palm oil (11). To enable compliance with such procurement policies, the RSPO would need to develop a clear definition of "deforestation" that can be monitored using remote sensing (27, 55). Remote monitoring (56) of conservation set-asides, supported by ground-truth assessments, could demonstrate compliance. The P&C would need to be revised to require that certified supply bases were not developed from peatlands and areas defined as forest. However, such changes would likely increase certification's cost, which threatens to exclude producers, especially small- and medium-size growers, from the RSPO (17). If membership stays stagnant or declines, the RSPO's impact on forest conservation and other critical sustainability concerns in the oil palm sector (e.g., workers' safety, water pollution) may decrease. Currently, the RSPO NEXT standard (57) allows producers that wish to meet zero deforestation commitments to become certified as no deforestation, no peat, and no fire. Such tiered standards may be preferable if the goal is to retain and gain RSPO members.

Our research indicates that palm oil producers currently have few incentives to expand the area of forest under their control. Thus, it is difficult to align individual corporate decisions with broader conservation goals, such as halting tropical deforestation (53). Positive incentives for forest protection, such as a price premium linked to forest conservation, may increase forest area preserved through certification. With around 20% of all global palm oil now certified (17), the RSPO has great potential to influence tropical land cover change. Whether roundtable members embrace higher levels of stringency and transparency around land use change, and how such changes might affect incentives for RSPO membership, will determine palm oil certification's contribution to tropical forest conservation.

## Methods

**Plantation Boundaries and Planted Oil Palm.** The RSPO secretariat supplied polygon vector data that outlined the boundaries of 134 of RSPO-certified supply bases worldwide. We digitized additional polygons from maps available from audit reports hosted on the RSPO website, and supplemented these with plantation boundaries provided in annual communications of progress (ACOPs). For noncertified plantations, we used oil palm concession leases (35)* supplemented with RSPO member-held noncertified concessions from ACOPs. We identified noncertified, RSPO member-held plantations by comparing company names from this database with names of RSPO member subsidiary companies. The noncertified dataset overlapped substantially with certified polygons, and we reconciled these geodatabases by modifying overlapping areas. Planted oil palm was derived from maps developed through manual digitization of plantations from satellite data (2, 40). Plantations in our dataset occurred across Indonesian regions, including Kalimantan, Sumatra, Papua, Sulawesi, the Riau Islands, the Maluku Islands, Nusa Tenggara, and Java.

**Forest Cover Loss and Fire Occurrence.** We aligned our forest loss outcome metrics as closely as possible with those in the RSPO certification system. We used 2001–2015 Landsat satellite-derived deforestation, defined as a stand-replacement disturbance or the complete removal of tree canopy cover, to assess deforestation, and primary and peatland forest loss (39). Since tree plantations may be indistinguishable from intact forest based on forest canopy cover (25, 49), we excluded areas identified as plantation and mixed tree crop from deforestation assessments (2, 40). We define forest as having >90% tree cover in 2000 (39). We chose this threshold to exclude agroforests, secondary forest regrowth, and other lower forest cover lands from deforestation metrics (49). This is particularly important in Indonesia, where agroforests, forest-like fallows, jungle rubber, pulp and paper, and oil palm have high canopy cover but are not targeted for conservation under the P&C (17). Sensitivity analyses explored the effects of alternate forest definitions (30% and 60% forest cover) on outcomes (Table S4). To evaluate the impact of certification on primary forest loss, we quantified tree cover loss (39) in areas of "primary forest," mature natural forest of ≥5 ha retaining natural composition and structure (38). We assessed the degree to which certified plantations were located on peat (58–60) and quantified forest cover loss in peatlands. We used the MODIS global monthly fire location product (MOD14 v6) to identify locations of active fire (37). To generate annual fire rates (fire detections per square kilometer per year) from 2002 to 2015, we summed annual fire detections in each plantation and divided by plantation area.

**Econometric Models.** To minimize selection bias (33, 61), we combined matching and panel methods (62). Matching methods control for observed differences (e.g., past fire rates) between certified and noncertified plantations before certification. Panel methods control for time-invariant characteristics of the plantation (e.g., ownership) and temporally varying shocks to the system (e.g., drought). Lagged models considered all plantations that have issued LOIs, including those not yet certified as of 2016, as "treated." We first excluded plantations with <1 $km^2$ of forest cover or >99% coverage by timber, rubber, oil palm, or other plantations in 2000. This eliminated all certified plantations outside of Kalimantan and Sumatra. We then calculated propensity scores for the remaining plantations using several observable characteristics (Table S1). Using these propensity scores, we matched certified plantations to similar noncertified plantations within Indonesian regions (i.e., Kalimantan and Sumatra). Alternate matching specifications constrained matches to fall within the same district or company. Next, we used a Poisson model with year and plantation fixed effects to quantify the average effect of certification on certified plantations (Tables S2, S5, and S6).



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We tested the robustness of our results against several alternate functional forms, definitions of deforestation, and geographic subregions (Table S4). We also tested the second-stage model's assumption of parallel trends among certified and noncertified plantations (Table S3).

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1. Henders S, Persson UM, Kastner T (2015) Trading forests: Land-use change and carbon emissions embodied in production and exports of forest-risk commodities. *Environ Res Lett* 10:125012.
2. Carlson KM, et al. (2013) Carbon emissions from forest conversion by Kalimantan oil palm plantations. *Nat Clim Chang* 3:283–287.
3. Nepstad D, et al. (2014) Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains. *Science* 344:1118–1123.
4. Gibson L, et al. (2011) Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature* 478:378–381.
5. Curran LM, et al. (2004) Lowland forest loss in protected areas of Indonesian Borneo. *Science* 303:1000–1003.
6. Marlier ME, et al. (2015) Fire emissions and regional air quality impacts from fires in oil palm, timber, and logging concessions in Indonesia. *Environ Res Lett* 10:085005.
7. Carlson KM, et al. (2014) Influence of watershed-climate interactions on stream temperature, sediment yield, and metabolism along a land use intensity gradient in Indonesian Borneo. *J Geophys Res Biogeosci* 119:1110–1128.
8. Wunder S, Angelsen A, Belcher B (2014) Forests, livelihoods, and conservation: Broadening the empirical base. *World Dev* 64(Suppl 1):S1–S11.
9. Kanowski PJ, McDermott CL, Cashore BW (2011) Implementing REDD+: Lessons from analysis of forest governance. *Environ Sci Policy* 14:111–117.
10. Lee J, Gereffi G, Beauvais J (2012) Global value chains and agrifood standards: Challenges and possibilities for smallholders in developing countries. *Proc Natl Acad Sci USA* 109:12326–12331.
11. Donofrio S, Rothrock P, Leonard J (2017) *Supply Change: Tracking Corporate Commitments to Deforestation-Free Supply Chains* (Forest Trends, Washington, DC).
12. Walker N, Patel S, Davies F, Milledge S, Hulse J (2013) *Demand-Side Interventions to Reduce Deforestation and Forest Degradation* (International Institute of Environment and Development, London).
13. Gibbs HK, et al. (2015) Did ranchers and slaughterhouses respond to zero-deforestation agreements in the Brazilian Amazon? *Conserv Lett* 9:32–42.
14. Gibbs HK, et al. (2015) Environment and development. Brazil's soy moratorium. *Science* 347:377–378.
15. Macedo MN, et al. (2012) Decoupling of deforestation and soy production in the southern Amazon during the late 2000s. *Proc Natl Acad Sci USA* 109:1341–1346.
16. Heilmayr R, Lambin EF (2016) Impacts of nonstate, market-driven governance on Chilean forests. *Proc Natl Acad Sci USA* 113:2910–2915.
17. Garrett RD, Carlson KM, Rueda X, Noojipady P (2016) Assessing the potential additionality of certification by the round table on responsible soybeans and the roundtable on sustainable palm oil. *Environ Res Lett* 11:045003.
18. Food and Agriculture Organization of the United Nations (2017) FAOSTAT online statistical service. Available at www.fao.org/faostat/en/#home. Accessed October 16, 2017.
19. Gaveau DL, et al. (2016) Rapid conversions and avoided deforestation: Examining four decades of industrial plantation expansion in Borneo. *Sci Rep* 6:32017.
20. Koh LP, Miettinen J, Liew SC, Ghazoul J (2011) Remotely sensed evidence of tropical peatland conversion to oil palm. *Proc Natl Acad Sci USA* 108:5127–5132.
21. Turetsky MR, et al. (2015) Global vulnerability of peatlands to fire and carbon loss. *Nat Geosci* 8:11–14.
22. Miettinen J, Shi C, Liew SC (2016) Land cover distribution in the peatlands of Peninsular Malaysia, Sumatra and Borneo in 2015 with changes since 1990. *Glob Ecol Conserv* 6:67–78.
23. High Conservation Value Resource Network (2017) HCV Resource Network. Available at www.hcvnetwork.org. Accessed October 16, 2017.
24. Carlson KM, et al. (2015) Consistent results in stream hydrology across multiple watersheds: A reply to Chew and Goh. *J Geophys Res Biogeosci* 120:812–817.
25. Carlson KM, et al. (2012) Committed carbon emissions, deforestation, and community land conversion from oil palm plantation expansion in West Kalimantan, Indonesia. *Proc Natl Acad Sci USA* 109:7559–7564.
26. Cattau ME, Marlier ME, DeFries R (2016) Effectiveness of Roundtable on Sustainable Palm Oil (RSPO) for reducing fires on oil palm concessions in Indonesia from 2012 to 2015. *Environ Res Lett* 11:105007.
27. Noojipady P, et al. (2017) Managing fire risk during drought: The influence of certification and El Niño on fire-driven forest conversion for oil palm in Southeast Asia. *Earth Syst Dynam* 8:749–777.
28. Laurance WF, et al. (2010) Improving the performance of the Roundtable on Sustainable Palm Oil for nature conservation. *Conserv Biol* 24:377–381.
29. Yaap B, Paoli G (2014) *A Comparison of Leading Palm Oil Certification Standards Applied in Indonesia* (Daemeter, Bogor, Indonesia).
30. Grassroots; EIA (2015) *Who Watches the Watchmen?* (Environmental Investigation Agency, London).
31. Greenpeace International (2013) *Certifying Destruction: Why Consumer Companies Need to Go Beyond the RSPO to Stop Forest Destruction* (Greenpeace International, Amsterdam).
32. Milder JC, et al. (2015) An agenda for assessing and improving conservation impacts of sustainability standards in tropical agriculture. *Conserv Biol* 29:309–320.
33. Imbens GM, Wooldridge JM (2009) Recent developments in the econometrics of program evaluation. *J Econ Lit* 47:5–86.
34. Ferraro PJ (2009) Counterfactual thinking and impact evaluation in environmental policy. *New Dir Eval* 2009:75–84.
35. Greenpeace (2016) Palm oil concessions. Available at www.greenpeace.org/seasia/id/Global/seasia/Indonesia/Code/Forest-Map/en/index.html. Accessed January 30, 2017.
36. Roundtable on Sustainable Palm Oil (RSPO) (2013) RSPO concessions. Available at commodities.globalforestwatch.org/. Accessed January 30, 2017.
37. Giglio L, Schroeder W, Justice CO (2016) The collection 6 MODIS active fire detection algorithm and fire products. *Remote Sens Environ* 178:31–41.
38. Margono BA, Potapov PV, Turubanova S, Stolle F, Hansen M (2014) Primary forest cover loss in Indonesia over 2000–2012. *Nat Clim Chang* 4:730–735.
39. Hansen MC, et al. (2013) High-resolution global maps of 21st-century forest cover change. *Science* 342:850–853.
40. Gunarso P, Hartoyo ME, Agus F, Killeen TJ (2013) Oil palm and land use change in Indonesia, Malaysia, and Papua New Guinea. *Reports from the Technical Panels of the Second Greenhouse Gas Working Group of the Roundtable on Sustainable Palm Oil*, eds Killeen TJ, Goon J (Roundtable on Sustainable Palm Oil, Kuala Lumpur, Malaysia), pp 29–63.
41. Slik JWF, et al. (2010) Environmental correlates of tree biomass, basal area, wood specific gravity and stem density gradients in Borneo's tropical forests. *Glob Ecol Biogeogr* 19:50–60.
42. Miteva DA, Loucks CJ, Pattanayak SK (2015) Social and environmental impacts of forest management certification in Indonesia. *PLoS One* 10:e0129675.
43. Blackman A, Goff L, Planter MR (2015) *Does Eco-Certification Stem Tropical Deforestation?* (Resources for the Future, Washington, DC).
44. Hardt E, et al. (2015) Does certification improve biodiversity conservation in Brazilian coffee farms? *For Ecol Manage* 357:181–194.
45. Panlasigui S, Rico-Straffon J, Swenson J, Loucks CJ, Pfaff A (2015) Early days in the Certification of Logging Concessions: Estimating FSC's Deforestation Impact in Peru and Cameroon. Duke Environmental and Energy Economics Working Paper Series, Working Paper EE 15-05 (Duke University, Durham, NC).
46. Rueda X, Thomas NE, Lambin EF (2015) Eco-certification and coffee cultivation enhance tree cover and forest connectivity in the Colombian coffee landscapes. *Reg Environ Change* 15:25–33.
47. Roundtable on Sustainable Palm Oil (RSPO) (2015) Remediation and Compensation Procedure (RaCP) Related to Land Clearance Without Prior High Conservation Value (HCV) Assessment. Available at www.rspo.org/key-documents/. Accessed October 16, 2017.
48. Margono BA, et al. (2012) Mapping and monitoring deforestation and forest degradation in Sumatra (Indonesia) using Landsat time series data sets from 1990 to 2010. *Environ Res Lett* 7:034010.
49. Tropek R, et al. (2014) Comment on "High-resolution global maps of 21st-century forest cover change". *Science* 344:981.
50. van der Werf GR, et al. (2008) Climate regulation of fire emissions and deforestation in equatorial Asia. *Proc Natl Acad Sci USA* 105:20350–20355.
51. Republic of Indonesia (2014) Law of the Republic of Indonesia No. 39 Year 2014 about Plantations. Available at www.indolaw.org. Accessed October 16, 2017.
52. Waldman KB, Kerr JM (2014) Limitations of certification and supply chain standards for environmental protection in commodity crop production. *Annu Rev Resour Economics* 6:429–449.
53. Kremen C, et al. (2000) Economic incentives for rain forest conservation across scales. *Science* 288:1828–1832.
54. McCarthy JF, Vel JA, Afiff S (2012) Trajectories of land acquisition and enclosure: Development schemes, virtual land grabs, and green acquisitions in Indonesia's Outer Islands. *J Peasant Stud* 39:521–549.
55. Brown S, Zarin D (2013) Environmental science. What does zero deforestation mean? *Science* 342:805–807.
56. Lynch J, Maslin M, Balzter H, Sweeting M (2013) Sustainability: Choose satellites to monitor deforestation. *Nature* 496:293–294.
57. Roundtable on Sustainable Palm Oil (2016) RSPO NEXT Guidance Document. Available at www.rspo.org/certification/rspo-next. Accessed October 16, 2017.
58. Wahyunto S, Ritung, Subagjo H (2003) *Maps of Area of Peatland Distribution and Carbon Content in Sumatera, 1990-2002* (Wetlands International–Indonesia Programme & Wildlife Habitat Canada, Bogor, Indonesia).
59. Wahyunto BH, Bekti H, Widiastuti F (2006) *Maps of Peatland Distribution, Area, and Carbon Content in Papua 2000-2001* (Wetlands International–Indonesia Programme & Wildlife Habitat Canada, Bogor, Indonesia).
60. Wahyunto S, Ritung, Subagjo H (2004) *Maps of Area of Peatland Distribution and Carbon Content in Kalimantan, 2000-2002* (Wetlands International–Indonesia Programme & Wildlife Habitat Canada, Bogor, Indonesia).
61. Blackman A, Rivera J (2011) Producer-level benefits of sustainability certification. *Conserv Biol* 25:1176–1185.
62. Jones KW, Lewis DJ (2015) Estimating the counterfactual impact of conservation programs on land cover outcomes: The role of matching and panel regression techniques. *PLoS One* 10:e0141380.