



# Social and Environmental Impacts of Forest Management Certification in Indonesia

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## Abstract

In response to unsustainable timber production in tropical forest concessions, voluntary forest management certification programs such as the Forest Stewardship Council (FSC) have been introduced to improve environmental, social, and economic performance over existing management practices. However, despite the proliferation of forest certification over the past two decades, few studies have evaluated its effectiveness. Using temporally and spatially explicit village-level data on environmental and socio-economic indicators in Kalimantan (Indonesia), we evaluate the performance of the FSC-certified timber concessions compared to non-certified logging concessions. Employing triple difference matching estimators, we find that between 2000 and 2008 FSC reduced aggregate deforestation by 5 percentage points and the incidence of air pollution by 31%. It had no statistically significant impacts on fire incidence or core areas, but increased forest perforation by 4 km<sup>2</sup> on average. In addition, we find that FSC reduced firewood dependence (by 33%), respiratory infections (by 32%) and malnutrition (by 1 person) on average. By conducting a rigorous statistical evaluation of FSC certification in a biodiversity hotspot such as Indonesia, we provide a reference point and offer methodological and data lessons that could aid the design of ongoing and future evaluations of a potentially critical conservation policy.

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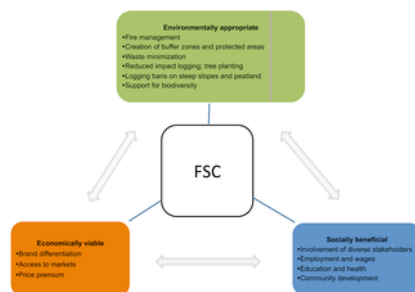
## Introduction

Tropical forests are of primary importance to biodiversity conservation and climate change mitigation [1,2]. However, in many locations they remain poorly protected and experience high levels of loss and degradation [3–5]. Timber production poses significant threats to forest ecosystems in tropical regions and Indonesia in particular [4,5]. For example, between 2000 and 2010 1.8Mha of forests (12.8% of all deforestation during that time period) were lost within commercial logging concessions in the country, with Kalimantan (the Indonesian part of the island of Borneo) being the most severely affected island [6]. Even selective logging can lead to degraded forests with low species richness [7].

Like in many other locations, establishing tenure in the form of forest logging concessions has often not been effective due to conflicting incentives and ineffective government responses [8,9]. In principle, traditional concessions employ the Indonesian Selective Cutting and Planting System (TPTI), which sets rotation time and the diameter of the harvested trees, necessitates replanting in the presence of low natural restocking rates and bans on logging on sensitive areas, but does not require reduced logging techniques [10]. However, the TPTI implementation has been flawed [10]. Furthermore, even when logging companies hold the formal rights over concessions, communities living in or around the concession land, especially those that are reliant on natural resources for their livelihoods, can also contribute to deforestation and degradation [11,12]. For example, in Berau District (East Kalimantan), about 150,000 cubic meters of timber (21% of all timber from the district) in 2000 were harvested by different illegal operations involving local communities [11]. These trends are likely to persist in Indonesia: Timber has become a significant source of revenue both for local governments and local communities because of the political and administrative decentralization process that began in 2001, coupled with the weak enforcement capabilities of the government [13,14]. Thus, because of mismanagement, deforestation and forest degradation due to uncontrolled logging and wildfires combined with the conversion of logged forests into oil palm plantations, the area of traditional logging concessions decreased from 59 million ha in 1990 to 25 million ha in 2011 [10].

In response to unsustainable practices in traditional logging concessions in Indonesia and elsewhere, companies have sought to adopt voluntary forest certification under which sustainable timber harvesting can become means to conserve forests and its species, while engaging and providing for local communities [9, 13–15]. Certification is based on the idea of creating incentives for sustainable forest management by providing a price premium or reputational benefits to the timber producers engaging in sustainable forest management as well as allowing access to markets that may be closed to timber producers with unsustainable forest practices [9, 16].

We focus on evaluating the performance of the Forest Stewardship Council (FSC) forest management certification program in Kalimantan, Indonesia. Initiated by non-governmental conservation organizations, the FSC program emerged in 1993 to promote the sustainable management of forests globally [9]. The general goals of the FSC program are to achieve “environmentally appropriate”, “socially beneficial”, and “economically viable” timber harvesting in logging concessions [17]. In addition to providing incentives to companies to incorporate the social costs of timber production, the FSC certification criteria emphasize compliance with law and international agreements; tenure security and conflict resolution among stakeholders; recognition of indigenous people’s land rights; community relations and workers’ rights; investments to maintain biodiversity; the ecological productivity of the area; minimized waste and damage to other resources like soil and water due to road construction; enhanced forest regeneration, monitoring and assessments of impacts of activities; and maintenance of high conservation value forests [17] (Fig 1).



**Fig 1. Summary of the intended FSC impacts.**

The arrows indicate linkages between the three goals. For example, reduced ambient pollution can reduce the incidence of diseases and hence household expenditures, increasing household welfare. The figure is based on [9, 18, 20].  
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Our review of the published background papers and grey literature on Indonesian FSC [18–20] suggests that to promote environmentally responsible logging, the FSC concessions adopt reduced impact practices of selective logging and tree planting (*Tebang Pilih Tanaman* and/or *Tebang Pilih Tanaman Jalur*), improved fire management, winch-based reduced skidding, and waste minimization. In addition, the FSC concessions in the country often include riparian buffer zones, areas with steep slopes or peat, reserves and protected areas that are maintained by the concessionaires but cannot be logged. The social goals are achieved through the employment of local workers and appropriate compensation as well as by implementing programs to improve education, health care, infrastructure, and community development (e.g., *Pembinaan Masyarakat Desa Hutan*—Forest Village Development Program). The FSC operations in Indonesia also implement general programs and commit specific resources to local communities that are affected by FSC [18].

Despite the recent proliferation of tropical forest management certification in Indonesia and elsewhere [21], there is almost no causal evidence about their performance promoting sustainable forestry and development in the impacted areas [20, 22, 23]. Because FSC concessions are not randomly established, an increasingly popular way to assess causality is through rigorous quasi-experimental techniques that use a mix of baseline measurements and other observable features (often called covariates) for FSC to identify non-FSC ‘controls’. These controls stand in for what would have happened to a FSC plot, had it not been certified (also referred to a “counterfactual”) [20, 24, 25]. By controlling for issues like price trends and threat from deforestation, these quasi-experimental techniques lead to statistically rigorous evidence about the performance of a conservation intervention [20, 24–26].

Very few studies have attempted to examine the causal impacts of the FSC program using a quasi-experimental approach. Brandt et al (2014) examine how the source of foreign capital (which presumably could influence the extent of compliance with sustainable forestry) impacts deforestation in the Congo basin, but do not focus on policies per se, including FSC certification [27]. Using data from community forest management associations in Acre, Brazil, de Lima et al (2008) to find some evidence that FSC increased awareness of regulations and management plans, better waste disposal, better use of fire, and restrictions on hunting [28]. Medjibe et al (2013) examine whether number of damaged trees, length of skid trails, width of logging roads, changes in species composition and loss in the above-ground-biomass is different on a FSC certified plot compared to adjacent conventional logging plot in Gabon [29]. Cerutti et al (2011) argue that FSC reduced harvested timber volumes by 18% in Cameroon [30]. However, the design of the latter two studies does not allow for statistically rigorous inference. Collectively, these studies confirm the lessons from recent reviews of better management practices for timber and for forest certification that very few studies use a statistically rigorous empirical design in general, focus on tropical forests and on Asia [20, 23, 31].

Following numerous calls for evaluating the performance of certification programs [20, 23, 32], we present the first statistically rigorous evaluation of the environmental and socio-economic impacts of FSC certification in Kalimantan. To our knowledge, this is one of very few studies filling the important knowledge gap regarding whether or not FSC helps preserve forests and improves the socio-economic dimensions of human wellbeing in a setting where it potentially matters most. Compared to our effort, most of the literature comprises of consulting reports with unknown scientific protocol for data collection and analysis, micro-ecological studies of limited scale (e.g., a few plots in idiosyncratic landscapes) and limited scope (e.g., ignore poverty and other socio-economic outcomes) or rhetorical policy opinion pieces. More generally, our work responds directly to recent reviews and calls for rigorous evaluation of conservation policies [26, 33, 34].

## Materials &amp; Methods

## Time period and region

We focus on the impact of the FSC forest management certification program between 2000 and 2008 in Kalimantan (Fig 1, Table 1). A blend of practicality and innovation influenced the choice of data used in our analysis. For example, the spatial and temporal frames were determined by the data availability. Because only two FSC concessions were established outside Kalimantan (in Sulawesi and Sumatra) prior to 2008 and because there are no reliable spatial boundaries for the original (pre-2008) concessions in Sumatra and Sulawesi, we did not include them in our analysis. While some firms applied for FSC certification as early as 2000, most completed the process in 2006 (or very close to 2006). For this reason, we use 2006 to mark of the start of FSC certification for the concessions in our sample and treat the year 2000 as our baseline.

| Concession                                | Year concession certified | Year concession allocated | Area certified (ha) | Primary Products   | Ownership   |
|---|---------------------------|---------------------------|---------------------|--|---|
| PT Inseka Wood Int                        | 2006                      | 1988                      | 194,230             | Plywood  | PT Inseka (24.7%), PT Alhaka '78 (48.9%), PT Sema Indonesia (24.7%), PTM Employees Cooperative (1.6%), PT SMI (20.0%) |
| PT Sari Bumi Kusuma (Dan 3 Block Sarawak) | 2007                      | 1988                      | 144,729             | Plywood, Barkless decking and moulding products  | PT Sari Bumi Kusuma (100%)  |
| PT Bumiwahi Lestari                       | 2006                      | 1981                      | 257,793             | Wood panels, plywood, solid wood veneer  | PT Bumiwahi Lestari (100%)  |
| PT Kima Djalawa                           | 2005                      | 1988                      | 160,489             | Customized flooring, back flooring, plywood, fancy panels and door skin, engineered flooring | PT Kima Djalawa (100%)  |

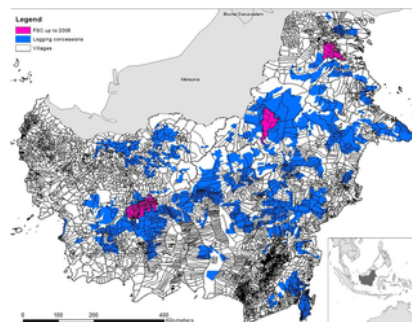
The logging concessions (HPH) are allocated for 30–70 years. As of 2008, in Indonesia the forest management FSC certification spans about 4.1% of the forest area designated for logging.  
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**Table 1. List of the FSC certified plots in Kalimantan by 2008.**

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## Unit of Analysis and Treatment Definition

As the unit of analysis we use a village, which is combination of human settlements and adjacent land as mapped by the Indonesian census. There are three main reasons for this choice. First, as there is no unclaimed land, the village areas sit entirely within concessions area (Fig 2). Because FSC impacts forests through both reduced impact logging and the creation and support of protected areas important to the provision of clean water or biodiversity (Fig 1), our ecological indicators (e.g., deforestation and forest fragmentation) capture the cumulative impacts of any FSC activities at the village level. While a pixel-level analysis can also capture the impacts of reduced impact logging by matching observationally similar pixels within the production portions of FSC and traditional logging concessions, it is likely to miss the impacts of the forest protection activities of FSC concessions. Second, village-level characteristics (e.g. poverty levels and population density) are likely to affect the performance of a FSC certified concession. However, a pixel or another purely spatial unit does not have socio-economic-political characteristics. If we were to account for the socio-political and economic characteristics (see discussion of confounders below), we would have to either assign the same values to each pixel that falls within the same village or use some spatial statistical algorithm to interpolate them. Either procedure would raise concerns about auto-correlation of spatially proximal pixels, especially if there is a spatial weighting process for assigning socio-economic values to pixels. Third, since many of the goals of FSC target communities, a pixel has no socio-economic meaning.



**Fig 2. Distribution of the logging concessions in Kalimantan.**

The FSC concessions established prior to 2008 appear in pink. The dark blue polygons are all logging (HPH) concessions established by 2008. A village is considered treated if it overlaps with a FSC forest concession; similarly, a control village is one intersected by an HPH concession.

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The treated group comprises all villages in Kalimantan that partially or fully overlap with a FSC concession established prior to 2008 (Fig 2). As the control group, we use all villages inside or intersected by traditional logging (Hak Pengusahaan Hutan (HPH)) concessions in Kalimantan. The plots in the control villages were not certified under FSC or the Indonesia Ecolabel Institute (LEI), which is an Indonesian standard consistent with FSC, by 2008 [35]. Field studies and annual audits conducted by the Rainforest Alliance are the primary source of details on the practices within logging concessions for our study area [16]. Some external verification comes from a different study on only a subset of the concession plots we consider in this paper (e.g., [19]).

## Covariates

We focus on the village characteristics that are likely to influence both (a) the placement of FSC concessions and (b) the outcomes. Following the growing literature on quasi-experimental methods, our selected covariates include population density, poverty levels, the length of the river network within a village as rivers can be used for transporting the harvested timber, the type of property rights (private ownership and customary land ownership proxied by the village area under a property rights regime divided by the village

area) within a village, proximity to markets and mills, slope, elevation, baseline forest cover, peat land area, and village area falling under Protected Areas (Table 2). The proximity to markets is proxied by distance to major cities, distance to province capitals, distance to the nearest market with permanent structures, and the distance to the nearest port interacted with the sea depth at the port, in order to distinguish between ports based on their commercial importance (larger vessels necessitate deeper ports). These are consistent with previous recommendations [20]. All of the covariates refer to the year 2000 and, therefore, to the period prior to certification. Descriptive statistics for the covariates are reported in S2 Table.

| Variable (Variable codes in parentheses)          | Definitions  |
|---|--|
| Average slope                                     | Average slope within a village, in degrees   |
| Average elevation                                 | Average elevation for a village, in meters   |
| Fraction village under protection                 | Fraction village area under any designated protected area  |
| Distance to major city                            | Euclidean distance from the village boundary to the nearest district capital or major trading centers, in meters     |
| Distance to capital                               | Euclidean distance from the village boundary to the nearest province capital, in meters                              |
| Distance to ports*depth of port (distports*depth) | Euclidean distance from the village boundary to nearest port (in km)*sea depth at the port (in km)                   |
| Length of the river                               | Length of the river network within a village, in meters  |
| Distance to permanent markets                     | Proximity to the nearest market with permanent structures. Based on PODES, in km.                                    |
| Population density                                | #people/village area. Based on PODES   |
| Poverty rate                                      | #Poor households/Total households within a village   |
| Distance to mills                                 | Euclidean distance to the nearest processing mill, in meters   |
| Fraction village area under peat                  | Unless   |
| Fraction village area under customary ownership   | Unless. Calculated as area under customary ownership/total village area as reported by the Indonesian Village Census |
| Fraction village area under private ownership     | Unless. Calculated as area under private ownership/total village area as reported by the Indonesian Village Census.  |
| Village area (vl_area)                            | In hectares  |

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**Table 2. Definitions of the covariates used in the analysis.**

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### Outcomes

The performance of FSC certification in terms of achieving environmental and social goals is the focus of this paper. We evaluate the impact of FSC on three sets of indicators: (1) Environmental: change in the amount and distribution of forest cover, incidence of forest fires, air and water pollution; (2) Household welfare: fuelwood dependence, incidence and levels of malnourishment, the incidence of acute respiratory infections (ARI); and (3) Village development: village infrastructure and the availability of funding for the village. Detailed descriptions of the outcomes are presented in Table 3. The multiple period data (2000, 2006 and 2008) allow us to compare absolute changes as well as the rates of change pre- and post-certification.

| Outcome  | Definitions   |
|--|---|
| Average forest cover   | Average % forest within a village, range 0–100; the dataset aims to exclude plantations and vegetation less than 5 meters in height. Source: MODIS  |
| Malnutrition   | #Individuals in 2008 suffering from malnutrition in the past 3 years. Calculated per village. Source: PODES   |
| Cumulative #Forest fires 2000–2008 on forest cells >40% forest | This is the #total village fires occurring on forest cells with >40% forest. Because the number of fires within a year varies depending on anthropogenic activity as well as on phenomena like El Niño and La Niña, we calculated the cumulative number of fires within the period. We experimented with different definitions of "forest fires": fires that occur on cells with specified % forest cover (10% or 40%), fires that fall within villages with at least some percent forest (10% or 40%). We also standardize the counts using the village areas under forest (using the 10 or 40% cutoff). These results are very similar to the ones included in the paper and are available upon request. Source: NASA FIRMS |
| Air pollution  | These are self-reported measures of whether or not air pollution was present in the village in a particular year (1 if air pollution present 0 otherwise). Source: PODES  |
| Water pollution  | These are self-reported measures of whether or not water pollution was present in the village in a particular year (1 if water pollution present 0 otherwise). Source: PODES  |
| Fuelwood   | Indicates whether the village relies on fuelwood as the main source of fuel (1 if fuelwood is primary, 0 otherwise). Source: PODES  |
| Availability of street lights in a village                     | 1 if available, 0 otherwise. Source: PODES  |
| Integrated Health Centers (IHC)                                | Number of integrated health center facilities within a given year. Source: PODES  |
| Incidence of Acute Respiratory Infections (ARI)                | 1 if there is at least 1 recorded incidence of ARIs within a village and 0 otherwise. Source: PODES   |
| Availability of private funding                                | 1 if funding from non-government domestic sources available in 2008, 0 otherwise. Source: PODES   |

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**Table 3. Definitions of the main outcomes.**

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The choice of environmental indicators directly follows from the FSC goals (Fig 1). We focus on the extent of habitat (forest cover), its structure (perforated area, core area) and indicators of environmental quality (forest fires, air pollution, water pollution). We would have preferred to have indicators of ecosystem function (e.g., the provision of hydrological services, pollination) or biodiversity. Unfortunately, wall-to-wall data on such indicators are non-existent at a fine resolution for most parts of the world, including our study site. The choice of our indicators for social and economic outcomes also balances the practicality of what is available with what is conceptually correlated with these outcomes. For example, we include three well measured and, therefore, frequently used indicators of socio-economic wellbeing, including the numbers of people in a community who: (i) suffer from malnutrition, (ii) suffer for acute respiration, and (iii) rely on fuelwood, which is a cheaper and dirtier cooking fuel in Indonesia [36]. Similarly, we also include indicators of village development and infrastructure (street lights, health posts and private finance) that best match the descriptions of the community programs in the Kalimantan FSC concessionaires [18].

While FSC in Kalimantan can be characterized as a complex coupled socio-ecological system, we chose these indicators also because they matched the FSC goals. For example, the FSC environmental goals of managing fires, creating buffer zones and protected areas, preventing logging on steep slopes, adopting reduced impact logging and tree planting could all reduce forest cover loss, while changing habitat structure. Similarly, the FSC economic goals of obtaining price premiums and market access, when combined with social goals of providing employment and wages, improving education and health, and conducting community development—could all collectively change household and community level wellbeing, proxied by the indicators listed above. These

could be direct or indirect to economic or environmental channels. Although there may be questions about the reliability of some of these proxy indicators, if our proxy is riddled with noise, then the noise would dominate the signal and we should see no impact of the policy. Thus, even though our estimates are conservative at best, we are not overstating the impacts of the program.

#### Data sources

##### Socio-economic data.

The socio-economic data used in the analysis come from the PODES datasets, which are village-level censuses carried out by the Indonesian government every 3 years to collect data on land use, population demographics, and village infrastructure for all nearly 69,000 villages in Indonesia. The village-level information is collected from the village leader (kepala desa or lurah, in rural and urban areas, respectively) by representatives of the Indonesian Bureau of Statistics [37,38]. Using a unique village identifier, we construct a panel consisting of the 2000, 2006, and 2008 PODES data. We use data from 2000 as our baseline as some FSC concession holders started the pre-certification compliance procedures shortly after. The latest PODES data we have are from 2008.

##### Forest cover data.

The forest cover data come from the MODIS Vegetation Continuous Fields datasets [39]. These datasets provide estimates of the percent tree cover within each cell at 250 m resolution for each year between 2000 and 2010. The main text presents the results for the change in forest cover between 2000 and 2008; the results using 2010 as the final year are presented in S4 Table.

##### Fire data.

We use data on the location of active fires using the NASA FIRMS datasets [40]. The datasets give the temporal and spatial distribution of active fires for the whole globe. We classified the fires into forest vs. non-forest fire categories based on the previous year's land cover pixel on which the fire point was located. This was necessary because of the annual level of aggregation of the forest cover data: Because we can only assign a forest cover value to a pixel for a given year and not for specific month/day, it is not possible to distinguish whether the fire event on a particular pixel preceded the measurement of the forest cover for that pixel within a given year. We used cumulative counts of the number of forest fires, between 2000 and 2008, in order to avoid bias associated with the choice of baselines because of the high inter-annual variability of fire incidence in Indonesia.

##### Physiographic data.

Data on the proximity to cities and ports, slope and elevation were collected from the World Resource Institute and the University of Georgia GIS data repository [41,42]. All distances are based on the Euclidean distance from the village edge to a city (port, mill) center.

##### Fragmentation data.

We conducted fragmentation analysis to assess the configuration of the landscape in terms of core and perforated habitat because these are important proxies for disturbance and species diversity and richness [43]. In order to calculate the fragmentation statistics for our study area, we reclassified the MODIS forest data using a 70% forest cover as the threshold defining forest. We chose 70% as the cutoff as the resulting forest area most closely resembled the previous estimates of forest area in 2000 [44]. Thus, cells with more than 70% forest were classified as forest and the rest as non-forest. We performed the analysis using a version of the Landscape Fragmentation Tool [45,46].

The tool classifies the forested pixels into 4 main categories: (1) "Edge"- forest pixels along the exterior perimeter of a forest that are often associated with higher tree mortality, high predation and introduced species (these are referred to as "edge effects") [47]; (2) "Patch", which comprises small isolated fragments of forest that are often degraded by edge effect; (3) "Perforated"-forest pixels along the edge of an interior gap in a forest that may be degraded by edge effects. In our study area these are likely the effect of selective logging; and (4) "Core", which includes interior forest pixels that are likely unaffected by edge effects (see S2 Fig for an illustration of the output). Because of the resolution of the original MODIS datasets, we used an edge distance of 250m.

#### Methods

FSC certification is a voluntary process. Historically, FSC plots have been established in areas with relatively low population density, higher poverty and in forests with more valuable timber [32,48]. To control for the endogenous (non-random) placement of the certification program, we apply matching methods that allow us to use existing data on non-certified villages, in order to infer what would have happened in villages overlapping FSC concessions, if FSC certification had not been introduced there [25]. The goal of the matching procedure is for each FSC village to find an observationally similar (in multivariate space) village within a traditional logging concession. Specifically, we use a Mahalanobis distance metric as our indicator of multivariate space and a nearest neighbor matching with replacement procedure [49]. The advantage of distance metric is that it gives more weight to covariates with smaller variances and smaller weights to noisier covariates. The procedure identifies the best match to a treated village based on the smallest distance between the treated village and a control village [49]. The causal impact of the program, the Average Treatment Effect on the Treated (ATT), is calculated as the average of the differences between the outcome for the treated village and the outcome for the matched control for each matched pair.

To improve covariate balance, we also apply trimming based on an estimated propensity score, which is the predicted linearized probability of FSC certification estimated in a logit model [50]. The logit model includes factors that (1) affect the placement of the FSC concessions and the outcomes, (2) have not been affected by the intervention, and (3) do not create misspecification issues like collinearity [51]. The actual variables used in this estimation are reported in S2 Table. The procedure allows us to ensure that the matches have a common support and eliminate observations with extreme values of the propensity score. We combine this trimming with matching based on the Mahalanobis nearest neighbor approach because it yielded the best covariate balance and the smallest remaining bias compared to a propensity score matching or a covariate matching using a Mahalanobis distance metric and no trimming. Post-matching, we apply linear bias adjustments to the ATT to remove any remaining differences in the covariate distributions [52–54]. We also correct the standard errors for heteroskedasticity within a treatment arm [53,54].

For the majority of outcomes we conduct difference-in-difference matching. Specifically, because we have data for most outcomes for three years (2000, 2006, and 2008) that correspond to time before certification, the year of certification, and time after certification, we apply triple-difference estimation. This approach uses as the outcome the difference between the differences in the outcomes between 2000 and 2006 and the differences in the outcomes between 2006 and 2008. Specifically, the outcome for each

group is constructed as  $(Y_{2000}-Y_{2006})-(Y_{2006}-Y_{2008})$ , where  $y_{200x}$  is the outcome for a given year. In other words, the approach compares the change in the outcome before certification to change in the outcome after certification for the treated and control villages.

The treatment effect for each matched pair is given by

$$[(y_{2000} - y_{2006}) - (y_{2006} - y_{2008})]_{\text{treated}} - [(y_{2000} - y_{2006}) - (y_{2006} - y_{2008})]_{\text{control}}$$

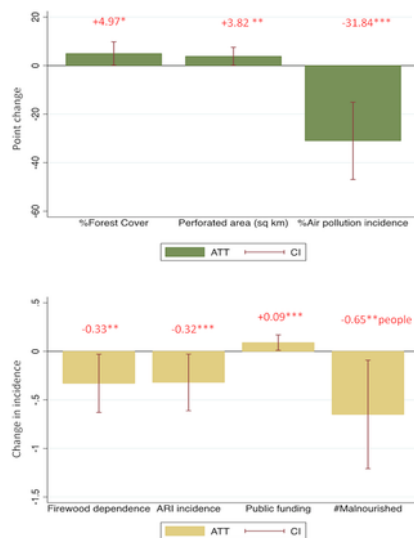
Thus, a positive ATT implies that the rate of change for the outcome for the treated group exceeds the rate of change of the outcome for the control group. In other words, if the outcome is a desirable one (e.g., % forest cover), a positive value tells us that, compared to before FSC certification, the introduction of certification led to a faster rate of forest cover increase in the treatment group compared to the matched controls. Note that in contrast to a simple difference-in-difference estimation, the ATT depends on the relative change of the outcomes between periods. In effect, we estimate a net reduction in deforestation through this procedure. For example, the raw data suggests that both FSC and non-FSC concessions experienced deforestation between 2000 and 2006, but that the FSC concessions showed faster recovery post-treatment compared to non-FSC concessions. The main advantage of our approach is that, while controlling for the observed characteristics, it allows us to eliminate unobserved time trends and not just time-invariant linear characteristics (eliminated by the more popular double difference estimators) that may be systematically different for the two treatment groups [55].

For a few of the development indicators, only cross-sectional data (data for a single year) were available. For those we employed cross-sectional matching, such that the treatment effect for a matched pair is  $y_{2008_{\text{treated}}} - y_{2008_{\text{control}}}$ , where  $y_{2008}$  is the outcome for 2008. Positive values in this case indicate that FSC increased the values of the outcome in the treated villages compared to the matched control villages.

## Results

The descriptive statistics of the covariates for the sample prior to matching (S1 Table) and the estimation of the propensity score used for trimming (S2 Table) identify some spatial features of FSC villages (*i.e.*, those spanned by FSC concessions). Relative to villages within traditional logging concessions, the FSC villages are located in isolated areas with lower population density, higher poverty rates, and closer to mills. Furthermore, they tend to have less peatland and shorter river networks (thus, fewer opportunities to transport illegal harvests). The non-random placement of the intervention justifies the application of a quasi-experimental technique like matching [52,56].

Fig 3 summarizes the statistically significant outcomes. In Table 4, we report our findings (ATT estimates) from the matching strategy on various outcomes. Note, the results are based on nearest neighbor matching using (a) Mahalanobis distance metric, (b) post-matching bias and variance correction, and (c) triple differences. We find that compared to villages in uncertified logging concessions, FSC certification in Kalimantan increased forest cover by about 5 percentage points in certified villages.



**Fig 3. Social and Ecological Impacts of FSC in Kalimantan.**

The heights of the columns represent the size of the impact; only statistically significant changes in the environmental (top) and socio-economic (bottom) outcomes are presented (if the error bars do not cross 0 (the x-axis), it suggests the impact was statistically significantly different from 0 (= no impact)). The impact of the program (ATT) is given in red above each bar. Significance levels: \*\*\*1%, \*\*5%, \*10%.

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| Outcome  | Mean treated | Mean controls | Bias Adj. ATT  | $N_t, N_{cm}, N_c$ |
|--|--------------|---------------|----------------|--------------------|
| Avg percent forest cover change 2000–2008 (SD)                 | 19.89        | 15.02         | 4.87**         | 6733/832           |
| Change in air pollution incidence b/w 2000 and 2008 (SD)       | -0.12        | 0.19          | -0.31***       | 6630/798           |
| Change in water pollution incidence between 2000 and 2008 (SD) | 0.12         | 0.22          | -0.10          | 6630/798           |
| Cumulative forest fires 2000–2008 on forest cells >40% forest  | 0.04         | 0.02          | 0.02           | 6733/832           |
| Perforated area (SD), in sq m                                  | 4,155,380.5  | 337,218.5     | 3,818,162.0**  | 6733, 832          |
| Core area (SD), in sq m  | 54,452,542.2 | 56,132,947.2  | (-1,680,405.0) | 6733, 832          |
| Change in fuelwood dependence 2000–2008 (SD)                   | 0.00         | 0.31          | -0.31**        | 6630/798           |
| Change in ARI incidence 2000–2008 (SD)                         | -0.12        | 0.26          | -0.38***       | 6630/798           |
| # Malnourished in 2008   | 0.30         | 0.34          | -0.04          | 6733/832           |
| Change in main street lights 2000–2008 (SD)                    | -0.11        | -0.07         | -0.04          | 6630/798           |
| Change in the #HC 2000–2008 (SD)                               | 0.42         | 0.26          | 0.16           | 6630/798           |
| Private funding available in 2008                              | 0.08         | 0.00          | 0.08***        | 6733/832           |

Tobin difference estimates are given as (SD). We provide robustness checks for the environmental outcomes using data for 2000–2010 in S4 Table.

Significance levels  
 \*\*\*p<.001,  
 \*\*p<.01,  
 \*p<.05,  
 †p<.10.

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**Table 4. Estimated treatment effects on the treated (ATT) for the selected environmental and socio-economic outcomes (heteroskedasticity-corrected standard errors (se) in parentheses)  $N_t$ ,  $N_{cm}$ , and  $N_c$  refer to the number of matched treated, matched control, and the control pool, respectively.**  
<http://dx.doi.org/10.1371/journal.pone.0129675.t004>

FSC also increased perforated areas. Collectively, these forest cover outcomes are indicative of selective logging within the certified concessions. We also find evidence that FSC reduced the incidence of air pollution within the treated villages, but did not have a statistically significant impact on the incidence of fires between 2000 and 2008. One potential explanation for the cleaner air but unchanged incidence of fires is that FSC reduced the intensity and emissions from fires, while having no statistically significant impact on fire incidence, which is a binary indicator and, thus, less statistically powerful. However, our data do not allow us to test this hypothesis.

Our results indicate that FSC certification also impacted household well-being. Compared to the villages within non-certified logging concessions, FSC reduced fuelwood dependence, the incidence of acute respiratory illness (ARI) and of malnutrition in 2008 (Table 4). Compared to the villages within non-certified concessions, FSC increased the village funding from private sources in 2008, consistent with the suggestions in the gray literature [18]. However, there is no statistically significant impact on the rates of providing infrastructure such as streetlights and health centers. A likely explanation is that infrastructure takes time to put in place.

Potential alternative explanations to the observed patterns could be that FSC induced differential migration, with poor sick forest-dependent people leaving the certified villages. If such people moved out of the FSC villages, we would observe increased household welfare and decreased forest loss. Alternatively, the observed forest cover patterns could also be attributed to FSC shifting the agricultural practices within a village away from swidden (ladang) cultivation. Despite our attempt to assemble a comprehensive data rich in many dimensions, we cannot rule out these happenstances. However, we can test for differences between FSC and control villages for some of these indicators. We fail to reject the null hypotheses that there are statistically significant differences in the rate of population change (ATT = -378.18, se = 378.97) or in the fraction of village land under agriculture (ATT = -0.13, se = 0.20). Thus, we did not find support that differential migration or decreases in ladang are driving our results.

#### Discussion

Our paper adds to the slowly growing literature on conservation policy impacts of forest certification. First, our example from Kalimantan employs several best practices in impact evaluations to reduce the bias in our estimate and strengthen our claim that we have measured the causal impacts of FSC certification. Second, while much of the literature has focused on protected areas, payments for environmental services or forest decentralization mostly in Latin America (e.g., Brazil, Costa Rica and Mexico), we are the first to consider certification—a potentially important tool for forest conservation—in a global deforestation hotspot such as Indonesia [23,33]. Finally, unlike the usual focus on aggregate deforestation and poverty outcomes, we respond to recent calls to better tailor impact evaluations by examining a variety of outcomes such as forest fragmentation, fire, air pollution, and community welfare, in addition to deforestation.

Using data from 2000–2008 in Kalimantan, we find that FSC certification significantly reduced deforestation by 5 percentage points and air pollution by 31% compared to the matched control villages in non-certified logging concessions. This suggests that the program may address previous concerns about the ineffectiveness of traditional logging concessions in reducing deforestation and their potential to decrease community welfare by limiting access to forest resources [9]. However, while FSC certification improves some environmental and socio-economic outcomes, the program may introduce disturbances in forest ecosystems (e.g., by opening the canopy).

It remains unclear if the FSC certification of logging concessions promotes biodiversity per se. Previous studies have found that sustainably managed forest concessions represent a “middle ground” between pristine habitats and logged areas [32], with the selectively logged forests in Kalimantan retaining a substantial fraction of the original species richness and diversity [57–61]. However, studies also document differential impact on species guilds. For example, Edwards et al (2009) found that forest rehabilitation of selectively logged forests in Kalimantan was beneficial to insectivorous birds, but detrimental to frugivores [58]. Mammal species are generally found to persist in selectively logged forests, despite lower abundances [60]. These studies suggest the impact of FSC certification will likely depend on the conservation goal (a few target species vs. species richness). Similarly, because FSC does not specifically target carbon in its guidance for certification or forest management requirements, in some cases it may not have significant impacts on reducing carbon emissions [19]. The impacts of FSC on the provision of other ecosystem services also remain unknown.

Because the sustainability of the FSC certification largely depends on the involvement of the local communities, it is important the program generates benefits to them [20]. We find that, compared to the villages in non-certified logging concessions, FSC in Kalimantan generated positive benefits to local communities (e.g., reduced disease incidence and fuelwood dependence, and

increased private funding). However, the data do not allow us to examine the mechanisms through which FSC effects change among villages. Establishing the mechanisms for change are important next steps in the design and implementation of FSC and conservation programs in general [33]. Further, we likely need more time to detect if FSC leads to noticeably better household and community outcomes (e.g., better public infrastructure), compared to the more sensitive and immediate environmental outcomes, especially for some of the more recent concessions (e.g., PT. Sari Bumi Kusuma). Despite being a relatively large sample study spanning multiple years, we do not have the luxury of studying only the older concessions. Thus, our estimates should be viewed as conservative estimates of early socio-economic impacts of FSC.

Owing to hurdles in obtaining certification and to the lack of explicit consideration of biodiversity and ecosystem service provision, FSC may not be an effective conservation or emissions mitigation policy by itself. However, because of the compatibility of REDD + and FSC requirements, FSC certification can be used as the stepping stone to receiving carbon payments that can be used to subsidize certification and make it accessible to more firms [22,32,62]. Another way to increase the effectiveness of FSC in preserving habitats may entail combining protected areas with FSC concessions [63] or with another intervention, especially in a way that promotes spatial coordination among targeted forests as opposed to the current concession-level planning for FSC forest management [32].

These conclusions lead us to re-emphasize the paucity of causal evidence of the performance of FSC certification and similar programs, despite their recent proliferation in tropical and non-tropical regions [64]. Maintaining the credibility of the FSC program necessitates rigorous empirical evaluations [20,65]. In contrast to the deforestation metrics that employ geospatial data, the socio-economic indicators of program performance and proxies for the impacts on biodiversity and ecosystem services are not readily available and necessitate on the ground surveys by independent third parties. Unfortunately, the current design of the FSC program does not require detailed data collection [20,65]. For this reason, we call for structural changes that make more and better data collection an integral part of the program implementation; this would facilitate evaluation of their effectiveness and long-term impacts, and, thus, improve conservation outcomes. In the meanwhile, we hope that the concepts, methods and data presented in this paper can expand and diversify the toolkit for evaluating a potentially important conservation policy, even as it serves as a point of reference and offers lessons for improving future research on forest certification, such as the coordinated effort by CIFOR currently underway [20].

#### Supporting Information

##### **S1 Appendix. Supplementary Information.**

The file contains additional robustness checks and background information.

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(DOCX)

##### **S1 Fig. Spatial distribution of the matched treated (n = 67) and matched control villages (n = 33).**

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(TIFF)

##### **S2 Fig. Illustration of the output from GUIDOS/Landscape Fragmentation Tool.**

In the analysis, we collapsed the three types of core areas into a single category.

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(TIFF)

##### **S1 Table. Descriptive statistics for the covariates used for matching (statistics reported for the unmatched sample).**

Absolute values for the normalized differences greater than 0.25 flag different covariate distributions [52].

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(PDF)

##### **S2 Table. Results from the first stage of the matching (logit model to generate the propensity scores).**

The dependent variable is whether or not a village falls under an FSC concession. Because of multicollinearity, the average % forest cover in 2000 was dropped from the analysis.

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(PDF)

##### **S3 Table. Covariate balance tests for the sample using only uncertified logging villages as controls.**

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(PDF)

##### **S4 Table. Results for the rate of change between 2000 and 2010 (triple differences).**

Standard errors are given in parentheses. Similar to the results for the period spanning 2000 and 2008, the outcome variable for each of the treatment arms is defined as (outcome 2000-outcome 2006)-(outcome2006-outcome2010). All the areas are defined in terms of square meters. A positive value indicates that FSC increased outcome (e.g., forest cover) in the treated villages relative to observationally similar non-FSC villages.

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(PDF)

##### **S5 Table. Changes in forest cover (triple differences) excluding protected zones.**

Standard errors are given in parentheses and the t-statistics-in brackets. Similar to previous results, the outcome variable for each of the treatment arms is defined as (outcome 2000-outcome 2006)-(outcome2006-outcome<sub>end year</sub>), where the end year is either 2008 or 2010. A positive value indicates that FSC increased forest cover in the treated villages relative to observationally similar



non-FSC villages.

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(PDF)

**S6 Table. Coordinates of the centroids of the concessions included in the study.**

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(PDF)

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#### Author Contributions

Conceived and designed the experiments: DAM CJL SKP. Performed the experiments: DAM SKP CJL. Analyzed the data: DAM SKP CJL. Wrote the paper: DAM CJL SKP.

#### References

- Gibbs HK, Brown S, Niles JO, Foley J. Monitoring and estimating tropical forest carbon stocks: making REDD a reality. *Environ Res Lett.* 2007; 2: 45023. doi: 10.1088/1748-9326/2/4/045023  
View Article • PubMed/NCBI • Google Scholar
- Pimm SL, Jenkins CN, Abell R, Brooks TM, Gittleman JL, Joppa LN, et al. The biodiversity of species and their rates of extinction, distribution, and protection. *Science.* 2014; 344: 1246752. doi: 10.1126/science.1246752. pmid:24876501  
View Article • PubMed/NCBI • Google Scholar
- Lawson S, Blundell A, Cabarle B, Basik N, Jenkins M, Canby K. Consumer goods and deforestation: an analysis of the extent and nature of illegality in forest conversion for agriculture and timber plantations. 2014. Available: <http://www.forest-trends.org/illegal-deforestation.php>.
- Sodhi NS, Koh LP, Brook BW, Ng PKL. Southeast Asian biodiversity: an impending disaster. *Trends Ecol Evol.* 2004; 19: 654–660. pmid:16701328 doi: 10.1016/j.tree.2004.09.006  
View Article • PubMed/NCBI • Google Scholar
- Wright SJ. The future of tropical forests. *Ann N Y Acad Sci.* 2010; 1195: 1–27. doi: 10.1111/j.1749-6632.2010.05455.x. pmid:20536814  
View Article • PubMed/NCBI • Google Scholar
- Abood SA, Lee JSH, Burivalova Z, Garcia-Ulloa J, Koh LP. Relative contributions of the logging, fiber, oil palm, and mining industries to forest loss in Indonesia. *Conserv Lett.* 2014; 8(1): 58–67. doi: 10.1111/conl.12103  
View Article • PubMed/NCBI • Google Scholar
- Slik JWF, Verburg RW, Keßler PJA. Effects of fire and selective logging on the tree species composition of lowland dipterocarp forest in East Kalimantan, Indonesia. *Biodivers Conserv.* 2002; 11: 85–98.  
View Article • PubMed/NCBI • Google Scholar
- Vincent JR. The tropical timber trade and sustainable development. In: Brown K, Pearce D, editors. *The causes of tropical deforestation: The economic and statistical analysis of factors giving rise to the loss of tropical forests.* Vancouver: UBC Press; 1994. pp. 298–308.
- Auld G, Gulbrandsen LH, McDermott CL. Certification schemes and the impacts on forests and forestry. *Annu Rev Environ Resour.* 2008; 33: 187–211. doi: 10.1146/annurev.enviro.33.013007.103754  
View Article • PubMed/NCBI • Google Scholar
- Ruslandi, Klassen A, Romero C, Putz FE. Forest Stewardship Council certification of natural forest management in Indonesia: Required improvements, costs, incentives, and barriers. Bogor, Indonesia: CIFOR. 2014. Available: <http://www.cifor.org/library/5106/forest-stewardship-council-certification-of-natural-forest-management-in-indonesia-required-improvements-costs-incentives-and-barriers/>.
- Casson A, Obidzinski K. From New Order to regional autonomy: shifting dynamics of “Illegal” Logging in Kalimantan, Indonesia. *World Dev.* 2002; 30: 2133–2151. doi: 10.1016/s0305-750x(02)00125-0  
View Article • PubMed/NCBI • Google Scholar
- Sills EO, Lele S, Holmes TP, Pattanayak SK. Nontimber forest products in the rural household economy. *Forests in a Market Economy.* 2003; 259–281.
- Resosudarmo IAP. Closer to people and trees: will decentralization work for the people and forests in Indonesia? In: Larson AM, Ribot JC, editors. *Democratic decentralization through a natural resource lense.* London; New York: Routledge; 2005. pp. 110–132.
- Burgess R, Hansen M, Olken BA, Potapov P, Sieber S. The political economy of deforestation in the Tropics. *Q J Econ.* 2012; 127(4): 1707–1754. doi:

10.1093/qje/qjs034

[View Article](#) • [PubMed/NCBI](#) • [Google Scholar](#)

15. Kiker CF, Putz FE. Ecological certification of forest products: economic challenges. *Ecol Econ.* 1997; 20: 37–51. pmid:10174062 doi: 10.1016/s0921-8009(96)00076-6  
[View Article](#) • [PubMed/NCBI](#) • [Google Scholar](#)
16. Araujo M, Kant S, Couto L. Why Brazilian companies are certifying their forests? *For Policy Econ.* 2009; 11: 579–585. doi: 10.1016/j.forpol.2009.07.008  
[View Article](#) • [PubMed/NCBI](#) • [Google Scholar](#)
17. Forest Council Stewardship. FSC principles and criteria. 2012. Available: <https://ic.fsc.org/principles-and-criteria.34.htm>.
18. Rainforest Alliance. Certified forestry operation summaries for Indonesia. 2014. Available: <http://www.rainforest-alliance.org/forestry/certification/transparency/operation-summaries-idn>.
19. Griscom B, Ellis P, Putz FE. Carbon emissions performance of commercial logging in East Kalimantan, Indonesia. *Glob Chang Biol.* 2014; 20: 923–937. doi: 10.1111/gcb.12386. pmid:24022913  
[View Article](#) • [PubMed/NCBI](#) • [Google Scholar](#)
20. Romero C, Putz FE, Guariguata MR, Sills EO, Cerutti PO, Lescuyer G. An overview of current knowledge about the impacts of forest management certification: a proposed framework for its evaluation. CIFOR. 2013. Available: [http://www.cifor.org/publications/pdf\\_files/OccPapers/OP-91.pdf](http://www.cifor.org/publications/pdf_files/OccPapers/OP-91.pdf).
21. Forest Council Stewardship. Global FSC certificates: type and distribution. 2014. Available: <https://ic.fsc.org/preview.facts-and-figures-september-2014.a-3534.pdf>.
22. Zagt RJ, Sheil D, Putz FE. Biodiversity conservation in certified forests: an overview. *Biodiversity conservation in certified forests.* 2010. Available: [http://pfb-cbfp.org/docs\\_rech-fr.html?file=docs/research\\_docs/ETFRN\\_51\\_Sept2010\\_CertificationandBiodiversity.pdf](http://pfb-cbfp.org/docs_rech-fr.html?file=docs/research_docs/ETFRN_51_Sept2010_CertificationandBiodiversity.pdf).
23. Blackman A, Rivera J. The evidence base for environmental and socio-economic impacts of "sustainable certification". 2010. Available: <http://www.rff.org/documents/RFF-DP-10-17.pdf>.
24. Milder JC, Arbutnot M, Blackman A, Brooks SE, Giovannucci D, Gross L, et al. An agenda for assessing and improving conservation impacts of sustainability standards in tropical agriculture. *Conserv Biol.* 2014; 29(2): 309–320. doi: 10.1111/cobi.12411. pmid:25363833  
[View Article](#) • [PubMed/NCBI](#) • [Google Scholar](#)
25. Pattanayak SK. Rough guide to impact evaluation of environmental and development programs. SANDEE. 2009. Available: [http://www.sandeeonline.org/uploads/documents/publication/847\\_PUB\\_Working\\_Paper\\_40.pdf](http://www.sandeeonline.org/uploads/documents/publication/847_PUB_Working_Paper_40.pdf).
26. Miteva DA, Pattanayak SK, Ferraro PJ. Evaluation of biodiversity policy instruments: what works and what doesn't? *Oxford Rev Econ Policy.* 2012; 28: 69–92. doi: 10.1093/oxrep/grs009  
[View Article](#) • [PubMed/NCBI](#) • [Google Scholar](#)
27. Brandt JS, Nolte C, Steinberg J, Agrawal A. Foreign capital, forest change and regulatory compliance in Congo Basin forests. *Environ Res Lett.* 2014; 9: 44007. doi: 10.1088/1748-9326/9/4/044007  
[View Article](#) • [PubMed/NCBI](#) • [Google Scholar](#)
28. De Lima ACB, Luiz A, Keppe N, Alves MC. Impact of FSC forest certification on agroextractive communities of the state of Acre, Brazil. 2008. Available: [http://www.rainforest-alliance.org/resources/documents/san\\_coffee\\_acre.pdf](http://www.rainforest-alliance.org/resources/documents/san_coffee_acre.pdf).
29. Medjibe VP, Putz FE, Romero C. Certified and uncertified logging concessions compared in Gabon: changes in stand structure, tree species, and biomass. *Environ Manage.* 2013; 51: 524–540. doi: 10.1007/s00267-012-0006-4. pmid:23277438  
[View Article](#) • [PubMed/NCBI](#) • [Google Scholar](#)
30. Cerutti PO, Tacconi L, Nasi R, Lescuyer G. Legal vs. certified timber: preliminary impacts of forest certification in Cameroon. *For Policy Econ.* 2011; 13: 184–190. doi: 10.1016/j.forpol.2010.11.005  
[View Article](#) • [PubMed/NCBI](#) • [Google Scholar](#)
31. Steering Committee of the State-of-Knowledge Assessment of Standards and Certification. Toward sustainability: the roles and limitations of certification. 2012. Available: <http://www.resolv.org/site-assessment/towardsustainability/>.
32. Putz FE, Zuidema P, Synnott T, Peña-Claros M, Pinard MA, Sheil D, et al. Sustaining conservation values in selectively logged tropical forests: the attained and the attainable. *Conserv Lett.* 2012; 5: 296–303. doi: 10.1111/j.1755-263x.2012.00242.x  
[View Article](#) • [PubMed/NCBI](#) • [Google Scholar](#)
33. Miteva DA, Pattanayak SK, Ferraro PJ. Do biodiversity policies work? The case for Conservation Evaluation 2.0. In: Helm D, Hepburn C, editors. *Nature in the Balance.* Oxford: Oxford University Press; 2014. pp. 251–284.
34. Ferraro PJ, Lawlor K, Mullan KL, Pattanayak SK. Forest Figures: Ecosystem Services Valuation and Policy Evaluation in Developing Countries. *Rev*

- Environ Econ Policy. 2011; 6: 20–44. doi: 10.1093/reep/rer019  
View Article • PubMed/NCBI • Google Scholar
35. LEI. Memorandum of understanding LEI-FSC. 2013. Available: <http://www.lei.or.id/mou-between-fsc-and-lei>; <http://www.lei.or.id/comparability-study-of-lei-and-fsc>.
36. Huboyo HS, Tohno S, Lestari P, Mizohata A, Okumura M. Characteristics of indoor air pollution in rural mountainous and rural coastal communities in Indonesia. *Atmos Environ*. 2014; 82: 343–350. doi: 10.1016/j.atmosenv.2013.10.044  
View Article • PubMed/NCBI • Google Scholar
37. RAND. Village Potential Statistics. 2014. Available: <http://www.rand.org/labor/bps/podes.html>.
38. Indonesia's Bureau of Statistics. Village Potential Statistics. 2014. Available: <http://pesselkab.bps.go.id/article/11-pendataan-podes-2014>.
39. DiMiceli CM, Carroll ML, Sohlberg RA, Huang C, Hansen MC, Townshend JRG, et al. Annual Global Automated MODIS Vegetation Continuous Fields (MOD44B) at 250 m Spatial Resolution for Data Years Beginning Day 65, 2000–2010, Collection 5, Percent Tree Cover. 2011. Available: <http://glcf.umd.edu/data/vcf/>.
40. FIRMS NASA. MODIS Active Fire Detections. 2012. Available: <http://earthdata.nasa.gov/firms>.
41. Minnemeyer S, Boisrobert L, Stolle F, Muliastira YIKD, Hansen M, Arunarwati B, et al. Interactive Atlas of Indonesia's Forests (CD-ROM); 2009.
42. University of Georgia data repository. 2014. Available: <https://gistdata.itos.uga.edu/>.
43. Turner M, Gardner RH, O'Neill RV. *Landscape ecology in theory and practice: Pattern and Process*. New York: Springer Verlag; 2001
44. World Bank. World development Indicators. 2013. Available: <http://data.worldbank.org/data-catalog/world-development-indicators>.
45. Vogt P, Riitters KH, Estreguil C, Kozak J, Wade TG, Wickham JD. Mapping Spatial Patterns with Morphological Image Processing. *Landsc Ecol*. 2007; 22: 171–177. doi: 10.1007/s10980-006-9013-2  
View Article • PubMed/NCBI • Google Scholar
46. Parent JR, Hurd JD. Landscape fragmentation tool (LTF) V2.0. 2013. Available: [clear.uconn.edu/tools/lft/lft2](http://clear.uconn.edu/tools/lft/lft2).
47. Fahrig L. Effects of Habitat Fragmentation on Biodiversity. *Annu Rev Ecol Evol Syst*. 2003; 34: 487–515. doi: 10.1146/annurev.ecolsys.34.011802.132419  
View Article • PubMed/NCBI • Google Scholar
48. Gullison RE. Does forest certification conserve biodiversity? *Oryx*. 2003; 37: 153–165. doi: 10.1017/s0030605303000346  
View Article • PubMed/NCBI • Google Scholar
49. Abadie A, Drukker D, Herr JL, Imbens GW. Implementing matching estimators for average treatment effects in Stata. *Stata J*. 2004; 4: 290–311.  
View Article • PubMed/NCBI • Google Scholar
50. Sekhon JS. Opiates for the matches: matching methods for causal inference. *Annu Rev Polit Sci*. 2009; 12: 487–508. doi: 10.1146/annurev.polisci.11.060606.135444  
View Article • PubMed/NCBI • Google Scholar
51. Caliendo M, Kopeinig S. Some Practical Guidance for the Implementation of Propensity Score Matching. *J Econ Surv*. 2008; 22: 31–72. doi: 10.1111/j.1467-6419.2007.00527.x  
View Article • PubMed/NCBI • Google Scholar
52. Imbens GW, Wooldridge JM. Recent developments in the econometrics of program evaluation. *J Econ Lit*. 2009; 47: 5–86. doi: 10.1257/jel.47.1.5  
View Article • PubMed/NCBI • Google Scholar
53. Abadie A, Imbens GW. Large sample properties of matching estimators for average treatment effects. *Econometrica*. 2006; 74: 235–267. doi: 10.1111/j.1468-0262.2006.00655.x  
View Article • PubMed/NCBI • Google Scholar
54. Abadie A, Imbens GW. Bias-corrected matching estimators for average treatment effects. *J Bus Econ Stat*. 2011; 29: 1–11. doi: 10.1198/jbes.2009.07333  
View Article • PubMed/NCBI • Google Scholar
55. Ravallion M. Evaluating anti-poverty programs. In: Schultz TP, John AS, editors. *Handbook of Development Economics Volume 4*. Elsevier; 2008. pp. 3787–3846.
56. Greenstone M, Gayer T. Quasi-experimental and experimental approaches to environmental economics. *J Environ Econ Manage*. 2009; 57: 21–44. doi:

10.1016/j.jeem.2008.02.004

[View Article](#) • [PubMed/NCBI](#) • [Google Scholar](#)

57. Cannon CH, Peart DR, Leighton M. Tree species diversity in commercially logged Bornean rainforest. *Science*. 1998; 281(5381): 1366–1368. pmid:9721105 doi: 10.1126/science.281.5381.1366  
[View Article](#) • [PubMed/NCBI](#) • [Google Scholar](#)
58. Edwards DP, Ansell FA, Ahmad AH, Nilus R, Hamer KC. The value of rehabilitating logged rainforest for birds. *Conserv Biol*. 2009; 23: 1628–1633. doi: 10.1111/j.1523-1739.2009.01330.x. pmid:19775274  
[View Article](#) • [PubMed/NCBI](#) • [Google Scholar](#)
59. Edwards DP, Larsen TH, Docherty TDS, Ansell FA, Hsu WW, Derhé MA, et al. Degraded lands worth protecting: the biological importance of Southeast Asia's repeatedly logged forests. *Proc R Soc B Biol Sci*. 2011; 278: 82–90. doi: 10.1098/rspb.2010.1062. pmid:20685713  
[View Article](#) • [PubMed/NCBI](#) • [Google Scholar](#)
60. Wilcove DS, Giam X, Edwards DP, Fisher B, Koh LP. Navjot's nightmare revisited: logging, agriculture, and biodiversity in Southeast Asia. *Trends Ecol Evol*. 2013; 28: 531–540. doi: 10.1016/j.tree.2013.04.005. pmid:23764258  
[View Article](#) • [PubMed/NCBI](#) • [Google Scholar](#)
- Arbainsyah , de longh HH, Kustiawan W, de Snoo GR. Structure, composition and diversity of plant communities in FSC-certified, selectively logged forests of different ages compared to primary rain forest. *Biodivers Conserv*. 2014; 23: 2445–2472. doi: 10.1007/s10531-014-0732-4  
[View Article](#) • [PubMed/NCBI](#) • [Google Scholar](#)
62. Brotto L, Murray J, Pettenella D, Secco L, Masiero M. Biodiversity in the Peruvian Amazon. In: Sheil D, Putz FE, Zagt RJ, editors. *Biodiversity conservation in certified forests*. Wageningen, the Netherlands: Tropenbos International. 2010. Available: <http://beahrselp.berkeley.edu/wp-content/uploads/2010/06/Biodiversity-conservation-in-certified-forests.pdf>.
63. Gaveau DLA, Kshatriya M, Sheil D, Sloan S, Molidena E, Wijaya A, et al. Reconciling forest conservation and logging in Indonesian Borneo. *PLoS One*. 2013; 8: e69887–e69887. doi: 10.1371/journal.pone.0069887. pmid:23967062  
[View Article](#) • [PubMed/NCBI](#) • [Google Scholar](#)
64. Sargent M. Global drivers of forest certification. M.Sc. Thesis, Duke University. 2014. Available: [http://dukespace.lib.duke.edu/dspace/bitstream/handle/10161/8543/SargentMargaret\\_MastersProject.pdf?sequence=1](http://dukespace.lib.duke.edu/dspace/bitstream/handle/10161/8543/SargentMargaret_MastersProject.pdf?sequence=1).
65. Blackman A, Rivera J. Producer-Level Benefits of Sustainability Certification. *Conserv Biol*. 2011; 25: 1176–1185. doi: 10.1111/j.1523-1739.2011.01774.x. pmid:22070273  
[View Article](#) • [PubMed/NCBI](#) • [Google Scholar](#)