APPLIED ECOLOGY

Fake legal logging in the Brazilian Amazon

Pedro H. S. Brancalion[1]*, Danilo R. A. de Almeida[1], Edson Vidal[1], Paulo G. Molin[2], Vanessa E. Sontag[1], Saulo E. X. F. Souza[1], Mark D. Schulze[3]

Declining deforestation rates in the Brazilian Amazon are touted as a conservation success, but illegal logging is a problem of similar scale. Recent regulatory efforts have improved detection of some forms of illegal logging but are vulnerable to more subtle methods that mask the origin of illegal timber. We analyzed discrepancies between estimated timber volumes of the national forest inventory of Brazil and volumes of logging permits as an indicator of potential fraud in the timber industry in the eastern Amazon. We found a strong overestimation bias of high-value timber species volumes in logging permits. Field assessments confirmed fraud for the most valuable species and complementary strategies to generate a "surplus" of licensed timber that can be used to legalize the timber coming from illegal logging. We advocate for changes to the logging control system to prevent overexploitation of Amazonian timber species and the widespread forest degradation associated with illegal logging.

INTRODUCTION

Tropical forests have been one of the main foci of the international environmental movement because of their importance in regulating climate and protecting biodiversity and because of the high rates of deforestation and degradation observed in recent decades (*1*, *2*). The Brazilian Amazon—the largest tropical forest worldwide—has become a global model for developing solutions to safeguard tropical forests (*3*) through creation of large protected areas (*4*), enforcement of environmental legislation (*5*), interventions in the soy and cattle supply chains (*6*), use of advanced technologies to monitoring deforestation by PRODES (Amazon Deforestation Monitoring Project) (*7*), and establishment of large logging concessions on public lands threatened by forest encroachment (*8*). Together, these strategies have worked to reduce deforestation rates by 76% from 2004 to 2017 (*9*). Illegal logging affects as much area as deforestation in the Brazilian Amazon (*10*, *11*) and is another major threat to biodiversity conservation in the region, as well as a catalyst for further degradation (*12*, *13*). The effectiveness of policy interventions to prevent illegal logging in the Amazon, however, is less known and difficult to measure. Remote sensing technologies have been developed to identify areas of illegal logging (*14*) and some obvious irregularities in authorized management plans (*15*), but no alternative is available for large-scale assessments of more subtle noncompliance with logging permits, such as deliberate overestimation of high-value timber species inventories.

Illegal logging is a huge barrier for using timber markets to promote sustainable use and conservation of forests. Forty-four percent (46,149 ha) of all tropical timber harvested between 2015 and 2016 in Pará—the largest timber production state in the Brazilian Amazon—was illegal (*15*). In an attempt to minimize illegal logging, the Brazilian government established a public forest concession system in 2006, which created opportunities for private entrepreneurs and communities to harvest timber on 23,844 km^2 of public forest land (*16*). On private landholdings, timber harvesting is regulated by specific legislation and by IBAMA (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis), the federal environmental agency. For mechanized logging, permits have to respect a maximum of 30 m^3 ha^{-1} timber yield in harvesting cycles of 25 to 35 years and a minimum felling diameter at breast height (DBH) of 50 cm (except when a specific DBH is assigned for a given species) and to retain commercial-size seed trees (at least 10% of large trees with commercial DBH in the area or three trees per 100 ha, whichever rule is more restrictive) (*17*). Legal timber harvesting, transportation, processing, and trading are tracked through the Document of Forest Origin (that is, paperwork formally required in each of these steps), which should, in theory, prevent fraud. Operationalizing this control system, however, has been problematic. The Pará state environmental agency has 55 forest officers to analyze, audit, and approve forest management applications in the 1.24-million-km^2 state (almost the size of Peru). The mismatch between the current staffing and the area of forest being logged prevents field checking of logging permits—an invitation for fraud and corruption. Remote monitoring and case studies suggest that various forms of fraud contribute to the continued prevalence of illegal logging (*15*, *18*). We investigated the potential role of one such form of fraud (that is, deliberate overestimation of high-value timber populations) in facilitating extraction and sale of illegal timber.

We evaluated evidence of fraud in the timber industry in the Brazilian Amazon based on the discrepancy between the estimated timber volumes in plots established by the government in undisturbed forests and the volumes of approved logging permits, as well as field assessments of six logged areas. We focused our analysis on Pará, eastern Amazon—the main timber production and export state. First, we integrated data of 427 valid logging permits issued from 2012 to 2017 in Pará, with 426 1-ha plots surveyed through the national forest inventory of Brazil (hereafter referred to as RADAM plots) (*19*) distributed across Pará state (fig. S1). From a total of 80 potential species, we selected 11 species or species groups (2 or 3 species sold with the same commercial name) with at least 50 observations in both logging permits and RADAM plots for comparison. These species represented a range of wood values and accounted for a total of 2.8 million m^3 of timber, 482,682 trees, and more than US$52 million of licensed timber (table S1). Discrepancy analyses were complemented by post-logging field assessments of six logging permits in western Pará accounting for a forest management area of 671,954 ha, in which the timber volume of ipê species (*Handroanthus* spp.) intended to be harvested in forest management area was much higher (>4 m^3 ha^{-1}) than those observed in RADAM plots (0.7 m^3 ha^{-1}).

[1]Department of Forest Sciences, Luiz de Queiroz College of Agriculture, University of São Paulo, Av. Pádua Dias, 11, Piracicaba, São Paulo 13418-900, PO Box 9, Brazil. [2]Federal University of São Carlos, Center of Nature Sciences, Rua Serafim Libaneo, 04, Campina do Monte Alegre, São Paulo 18245-970, PO Box 64, Brazil. [3]HJ Andrews Experimental Forest and Oregon State University, PO Box 300, Blue River, OR 97413, USA.
*Corresponding author. Email: pedrob@usp.br

RESULTS

The discrepancy between timber volumes registered in forest management units of approved logging permits and those observed in RADAM plots was positively correlated with timber price of standing trees, indicating a strong bias of potential overestimation of the most valuable timber species in logging permits (Fig. 1A). This pattern persisted when a more conservative analytical approach was used to compare timber volumes of low-, medium-, and high-value species of logging permits to quantile classes near the density distribution limit of those species' timber volumes in RADAM plots; we found that high-value species volumes exceeded the 90th percentile Amazon-wide inventory values in a larger proportion of logging permits than did volumes for less desirable timber species (Fig. 1B). Overall, the logging permits with potential overestimated timber volumes were spatially independent, which conflicts with the interpretation that higher timber volumes in logging permits are associated with specific regions where commercial timber species are more abundant (Fig. 2).

A minority of professionals were in charge of logging permits with higher probability of fraud (for example, with timber volume ratio in logging permits versus RADAM plots > 2), except for the most valuable species (*Handroanthus* spp.), for which most foresters registered much higher timber volumes in forest management units than those reported by RADAM plots (Fig. 3A). Four of the five species with the highest wood prices concentrated the most discrepant values (Fig. 3A), and the amount of variation among foresters increased with timber price (Fig. 3B). These results indicate that the general pattern of overestimated timber volumes in logging permits is strongly influenced by timber price and that a relatively small subset of professional foresters is associated with the most egregious overestimations.

Only 61% of the 152 trees identified as ipê species (*Handroanthus* spp.) in logging permits were confirmed during field checking of logged forests. The average proportion of botanical identification "mistakes" across the six areas was 42%, varying from no error in one site to 93.3% error in another. We found 13 commercial species "erroneously" identified as ipê, with low-value tanimbuca (*Terminalia* sp.), jarana (*Lecythis lurida*), and timborana (*Anadenanthera* sp.) being the most frequent (72.4% of the individuals); 85 ± 10% of the non-ipê trees were of species not included in the logging permit of the forest (that is, not considered valuable enough to harvest), which means that their harvesting was not anticipated or controlled and that the extra ipê volume garnered through "misidentification" could be easily used to mask illegal ipês. Ipê species are quite easy to identify and clearly distinguish morphologically (compound, palmate leaves) from the three species most frequently identified as ipê (simple leaves in jarana and tanimbuca and twice pinnate leaves in timborana), so misidentification can be attributed to fraud. In addition, we found that the diameter of real ipê trees was frequently overestimated. Overall, the stump diameters of 130 logged trees assessed in field checking were 31% smaller than the DBH claimed in logging permits, despite the fact that diameter measurements at stump height will almost always overestimate DBH. Naming other species as ipê and inflating tree diameter can be complementary strategies to generate a "surplus" of licensed ipê timber in logging permits to legalize the timber coming from illegal logging. Inventing trees, duplicating tree numbers, exceeding allowed harvest rates, and felling trees in forbidden zones (for example, reserve areas) were also observed, although less frequent. In all of the management areas investigated, we found evidence that the ipê timber volume reported on the Document of Forest Origin could not have been produced from that area alone while following harvest regulations.

DISCUSSION

The discrepancies between timber volumes from logging permits and RADAM plots may be associated with deliberate inflation of values to obtain the Document of Forest Origin to legalize timber extracted above authorized volumes, without maintaining the legal minimum

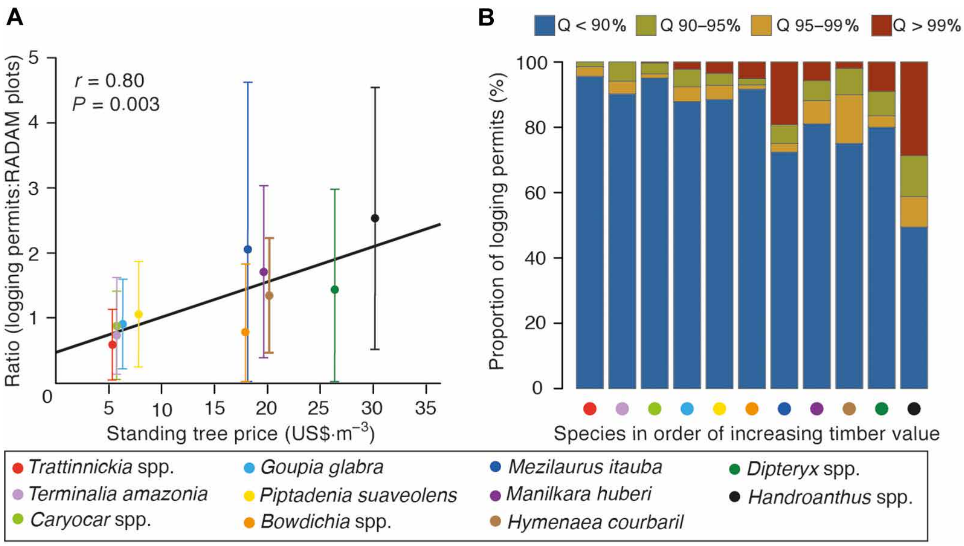

Fig. 1. Discrepancies in timber volumes between logging permits and RADAM plots. The discrepancy between timber volumes registered to be harvested in forest management units of approved logging permits and those observed in RADAM plots (that is, plots surveyed through the national forest inventory of Brazil) was positively correlated with timber price of standing trees (**A**), as was the proportion of logging permits with timber volumes located in the quantile classes of >90% (all colors except blue) of the density distribution of timber volumes of RADAM plots (**B**). Vertical error bars in (A) represent the SD.

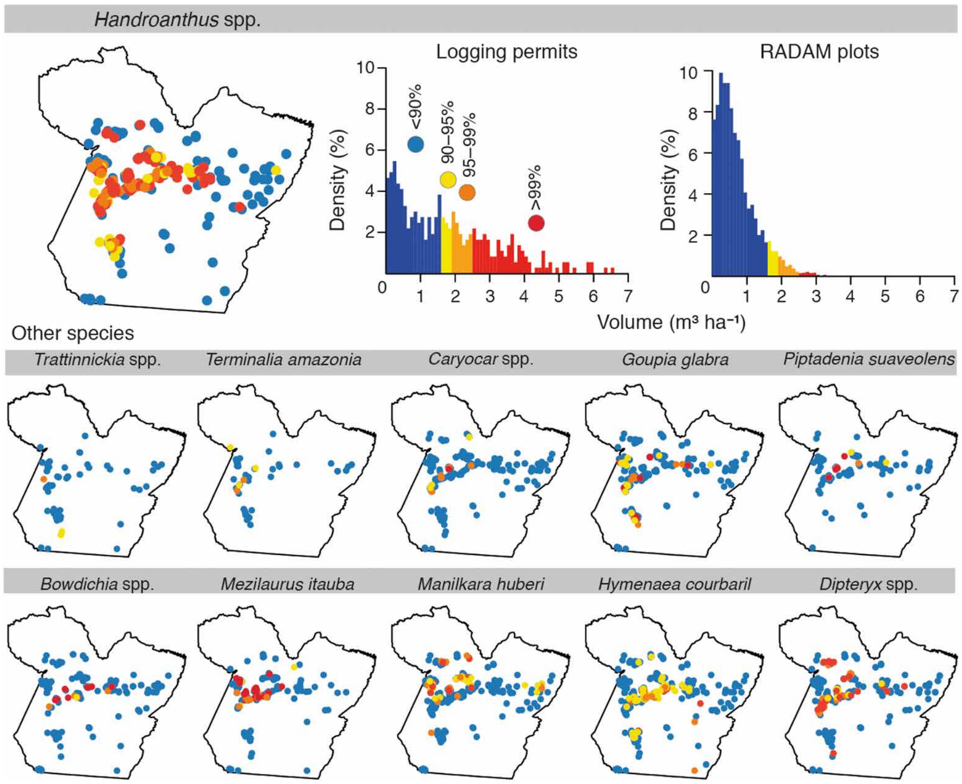

Fig. 2. Spatial distribution of logging permits according to their level of discrepancy in relation to RADAM plots. Distribution in the state of Pará of logging permits with timber volumes located in the quantile classes of >90% (all colors except blue) of the density distribution of timber volumes of RADAM plots (that is, plots surveyed through the national forest inventory of Brazil) of different Amazonian timber species. The top part of the figure shows the distribution of *Handroanthus* spp. Maps for other species are ordered from low- to high-value species from top left to bottom right in the layout.

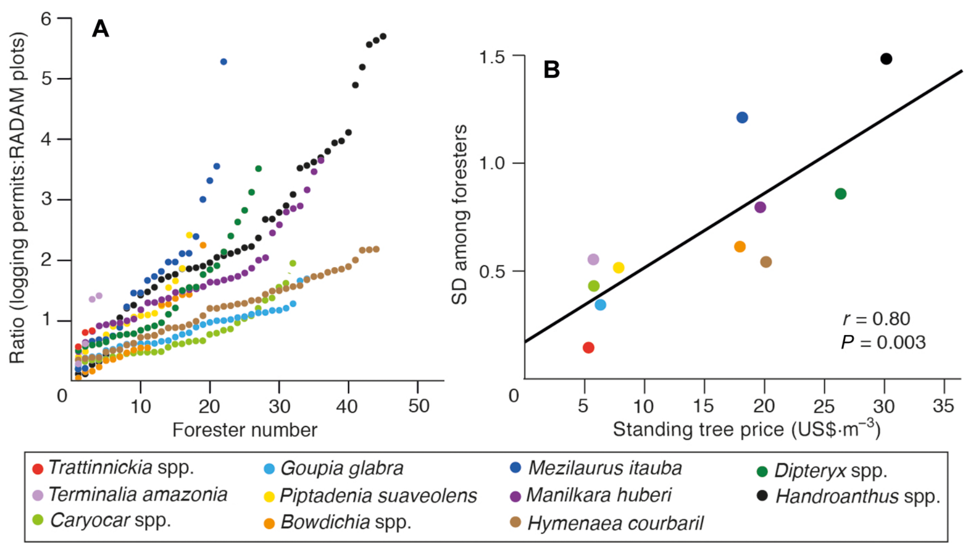

Fig. 3. Distribution of potentially fraudulent logging permits and overestimation variation among foresters. Distribution of the average ratio of timber volume in logging permits to RADAM plots (that is, plots surveyed through the national forest inventory of Brazil) of each forester in charge of logging permit, ordered from lowest to highest ratio for each species group on the *x* axis (**A**), and positive correlation between the SD of the ratios associated with different foresters and timber price of standing trees (**B**).

number of seed trees, and in areas where timber exploitation is not permitted. Ipê was by far the species with the strongest signal of potential fraud in logging permits. It is the internationally preferred timber for decking and one of the most expensive species in the market (*20*), with prices as high as those achieved historically by big-leaf mahogany (*Swietenia macrophylla* King) before commercial exploitation was prohibited in Brazil in 2001 to avoid the species' extinction. We found evidence that ipê is the "new big-leaf mahogany" and that overlogging may lead this species to extinction (*21*). This species is one of the most vulnerable to logging in Amazonian forests because of its natural low density and low growth rates (*21*). A total of 33,389 m^3 was licensed to be logged in 2017, and 74.2% of this volume has a high risk of being overestimated (that is, located in logging permits included in the quantile >95% of the density distribution of timber volumes; Fig. 2). This suggests that the issues observed in our field assessments are likely to be widespread.

Given the high probability of fraud in logging permits, we advocate supply chain interventions, following the examples of the soy and beef moratoriums implemented in the same region a few years ago (*6*). The timber moratorium would create the chance for the Brazilian Environmental Agency to revisit logging permits and check inconsistencies in the field, using the analytical framework presented here or another approach developed for this task. Field checking of logging plans is an essential component for preventing fraud. For instance, post-logging field inspections of forest concessions in the Peruvian Amazon resulted in the cancellation of almost half of inspected concessions due to major violations of existing norms (*22*). We are aware that a moratorium could cause economic setbacks to the Brazilian timber industry, which accounted for 85% of all neotropical production of roundlogs (*13*) and a total export value of US$600 million in 2016 (*23*). However, Brazilian law does not allow timber trading that comes at the expense of overexploitation and potential extinction of native trees. It is already known that current logging regulations applied to forest concessions in the Brazilian Amazon are not expected to safeguard the long-term conservation of timber species, given that most targeted species are rare and slow-growing (*13*). However, the apparent substantial overestimation of timber volumes in logging licenses could represent the "kiss of death" for species like ipê.

Frauds during timber harvesting licensing can occur as a result of negligence and corruption in several ways: (i) through the approval of logging activities in areas already exploited or deforested, (ii) issuing credits (that is, license to harvest timber) regardless of the authorized amount requested (even when impossibly large), (iii) registering fake tree inventories in the system to issue credits for timber companies that do not exist or do not have a forest to harvest legally, (iv) by obtaining credit for areas where there is no intention to log, and (v) overestimating the volume or density of valuable species (*24*). The illegal credits can be used to harvest, transport, and sell timber from unauthorized or prohibited logging areas. For example, around 90% of the illegally harvested area between 2008 and 2012 in Pará state was conducted in indigenous lands and protected areas (*25*). Fraudulent logging operations are generally detected in isolated operations of regulatory agencies, covering a small fraction of the forest area logged annually, and always after timber exploitation. The large-scale detection of frauds before timber harvesting and identification of foresters involved in these frauds, as allowed by the methodological approach used in this work and the web-based system proposed here, would be a strategic advance for imposing critical barriers to continuation of illegal logging in the Brazilian Amazon (Fig. 4).

The economic viability of sustainable timber management in the Amazon may rely on improving the public systems governing logging in native forests. The major competitor of legal logging is illegal logging, which pushes market timber prices down and undermines the necessary investments for reduced impact logging and enforcement of no-go zones. Although the timber moratorium could bring some relief to overexploited timber species, it will not solve the problem of the weak system used to control timber exploitation in the Amazon. Timber buyers should not rely solely on governments to reduce illegal logging. The timber market and other sectors of society should exert more pressure on governments to make the licensing processes fully transparent. The same is true for the existing chain of custody monitoring systems [for example, SINAFLOR (National System for the Control of the Origin of Forest Products) and SISFLORA (System for Marketing and Transporting of Forest Products) in Brazil] that are under the responsibility of state and federal environmental agencies. The Brazilian Federal Council of Engineering and Agronomy, which controls the activity of foresters, has the mandate to punish professionals involved in fraud and should make use of it. Certification schemes and emerging platforms to control timber origin (*26*) can also be part of the solution. On the other hand, a new control system is required and would be relatively easy to implement. The main problems currently observed in the present system—lack of consistency and standardization in species names, near-automatic approval of logging without previous field checking, and lack of integration among available databases on timber stocks and species distributions—could be partially resolved by creating a new web-based system to manage information (Fig. 4) and targeted field supervision of logging permits.

Scientific methods for timber identification and timber tracking have been developed to verify timber legality. These methods have mostly used visual identification (wood anatomy and dendrochronology), chemical approaches (mass spectrometry, near-infrared spectroscopy, stable isotopes, and radiocarbon dating), and genetic approaches (DNA barcoding, population genetics/phylogeography, and DNA fingerprint) (*27*). DNA technologies have been tested in several countries to combat illegal logging (*28*). In Indonesia, the integration of mandatory forest certification with the national system of legality of wood [SVLK (Sistem Verifikasi Legalitas Kayu)] has increased international credibility on the timber exploitation control system, since an independent auditor evaluates whether harvests are in accordance with the laws of the country (*29*). Other countries have their own systems for monitoring tropical timber chain of custody, and most of the successful cases involve field checking and stump inspection. The timber transportation control is usually made using travel permits. Thailand has checkpoints all over the country, some of which are open 24 hours a day. Suriname has developed a computerized log-tracking system called LogPro to monitor all information about harvest operations, payment of forest fees, and forest planning (*30*). Producers are required by law to provide detailed information concerning the production, which is registered twice in the system by two independent data processors. The system crosses information and checks incompatibilities, thus reducing the possibility of corruption.

Conserving Amazonian timber species requires a new model that includes enforcement and modernization of logging licenses, as well as meaningful engagement of all stakeholder groups. Conversion of paperwork to digital platforms would not only reduce the numerous problems caused by bureaucracy and the opportunities for corruption, it could also increase transparency and allow a better integration of existing databases to guide decision-making. In this context, scientists could partner with governments to develop effective solutions to environmental problems and reduce the gap between knowledge generation and application. Without a serious effort to address this issue, large-scale high-grading and degradation of Amazonian forests will continue.

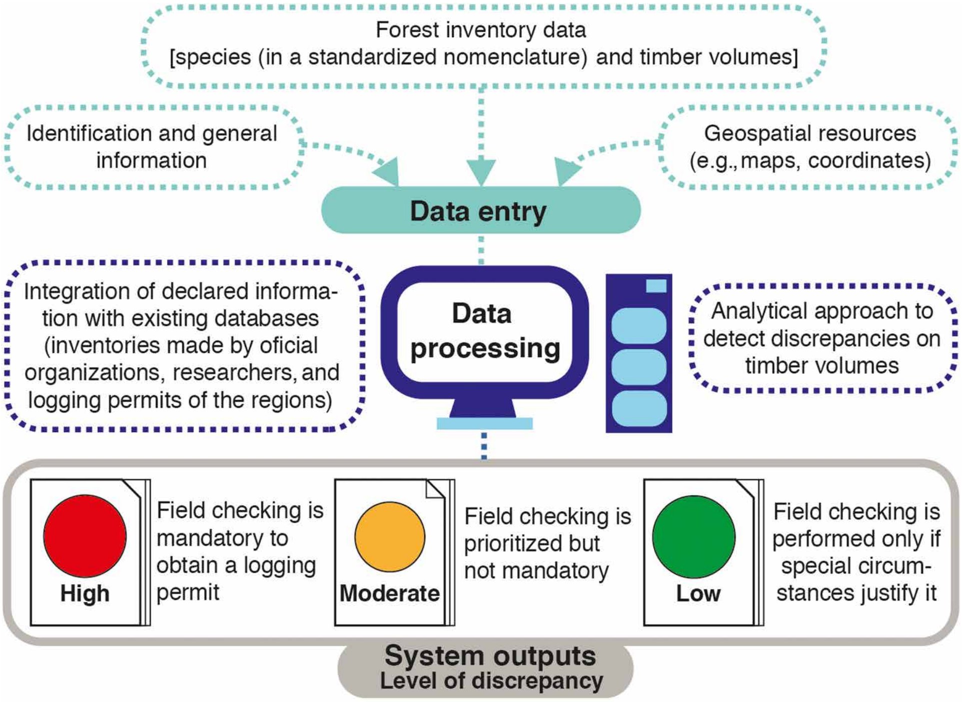

Fig. 4. Proposed web-based system to register and manage logging permits. This system would require the documentation of species based on predefined, standardized botanical or commercial names, their associated timber volumes, and geospatial information on their localization in licensed forests, which would be integrated in the system with existing databases to assess the levels of discrepancies of informed and expected timber volumes in forest management units of logging permits. Field checking of logging permits would be guided by this analysis to optimize the use of a limited staff to control large areas of forest concessions.

MATERIALS AND METHODS

Logging permits and official forest inventories

We gathered a total of 427 valid logging permits [AUTEF (Autorização de Exploração Florestal)] issued from 2012 to 2017 and available at the Integrated System for Monitoring and Environmental License [SIMLAM (Sistema Integrado de Monitoramento e Licenciamento Ambiental)] of the Environmental Secretariat of Pará. Logging permits classified as "canceled" or "suspended" were not considered. Each logging permit consisted of the list of species and respective timber volumes to be logged in the area licensed for timber exploitation (mean area of logging permits, 561 ha; range, 18 to 4552 ha) (fig. S1). The information presented in logging permits was obtained by the application of the legal norms on timber exploitation in native Amazonian forests (*17*) to a census of the area licensed for timber exploitation. We contrasted the timber volumes registered for harvest in forest management units of logging permits with those obtained by 426 spatially independent, 1-ha RADAM plots (DBH, ≥50 cm; fig. S1). These RADAM plots were not randomly distributed in Pará state because of the inaccessibility of the vast majority of areas of the dense Amazon forest. However, the RADAM protocols attempted to collect representative samples of the major vegetation types in each region and avoided sampling disturbed forests by largely sampling in areas accessible only by helicopter, as far as possible from roads and trails (*19*). Although larger inventory plots would be preferred to compare with logging areas, the RADAM inventory is still the best source of information available for wide-scale assessments of timber stocks, aboveground biomass, and tree species distribution in the Brazilian Amazon and has been used in many studies (*13*, *21*, *31*, *32*).

Timber species

The taxonomic identification of timber species in the Amazon is problematic, and a mix of different scientific and common names is used for a single group of commercial timber species. A total of 80 timber "species" were found in logging permits, from which we selected 11 species or species groups (two or three species sold with the same commercial name) for which we had at least 50 observations in both logging permits and RADAM plots (table S1). Timber prices of standing trees were obtained from (*33*), and monetary conversion was considered US\$1 = R\$3.15.

Field assessments

To validate the analytical approach used to identify potential overestimated timber volumes in logging permits, we performed field assessments of ipê (*Handroanthus* spp.)—the commercial species with the highest timber price and for which we found the highest likelihood of fraud—in logged forests. We first selected recent logging permits (issued from August 2016 onward) in western Pará, totaling ~100 logging permits. Then, we selected the 19 logging permits that presented >4 m^3 ipê timber per hectare, which also showed high discrepancy between estimated timber volumes of RADAM plots and the volumes of approved logging permits, and with volumes in the quantile classes of >95% of the density distribution of timber volumes. Finally, we selected six areas in accordance with the staff of IBAMA of the Ministry of Environment, which gave preference to small (~100 ha) areas planned to be harvested within just 1 or 2 years. These six areas represent small logging areas with a single annual production unit [Unidade de Produção Anual (UPA)], which comprise the majority of logging permits issued in Pará state. By the time field assessments are carried out, these areas had already been logged. Using the available documentation (forest surveys and maps) for each area, we randomly sampled the ipê trees listed in each area, which included both harvested and remnant trees. Standing trees were identified by observing vegetative materials, and the stumps were identified by observing external and internal bark traits and botanical attributes of shoots; when necessary, a piece of heartwood was collected with a chainsaw to examine its macroscopic anatomy. We measured the DBH of standing trees, and for logged trees, we calculated the mean diameter of each stump based on two perpendicular diameter measurements. Measurements of stump diameters were obtained at a height of ~45 cm, where the diameter is expected to be larger than that of the DBH. Therefore, our analysis was conservative, and higher diameter discrepancies would be expected if we had been able to measure actual DBH before harvest.

Statistical analysis

We calculated the average ratio between the timber volume of each species in logging permits and the mean timber volume of the same species in all plots of RADAM inventory as a strategy to identify discrepancies between them and use it as a proxy to detect potential fraud (that is, inflated timber volumes in logging permits). We are aware that some discrepancies are to be expected when comparing timber volumes estimated from small official plots distributed over a wide geographical area with those from inventories of large logging areas. However, we did not focus the interpretation of results on the absolute values of these discrepancies but rather on the "direction" and consistency (if timber volumes were generally underrepresented or overrepresented) and on the bias toward overestimating the most valuable species. Given that the timber volume estimates of logging permits are expected to omit some commercial-size trees of each species to satisfy the legal criteria of keeping at least 10% of large trees in the area or three trees per 100 ha (or 15% of large trees and four trees per 100 ha for species included in the official lists of threatened species for which timber harvesting is allowed) and that the RADAM inventory did not use any exclusion criteria, our analysis can be considered conservative with respect to overestimation detection. We then performed a Pearson correlation between the average ratio of logging permits to RADAM plots and timber prices. We also investigated the discrepancies between timber volumes of logging permits and RADAM plots using a different analytical approach based on the density distribution of simulated larger RADAM plots and logging permits. Since the official inventory of RADAM was based on smaller inventory plots (1 ha) than those used by the forest inventories associated with logging permits (18 to 4552 ha), we performed 10,000 randomizations of 19 1-ha plots (an area similar to the smallest logging permit inventory and one that makes a better histogram of timber volumes per species). We then generated histograms of official inventory/logging permit density distribution; assessed the proportion of logging permits with timber volumes included in the quantiles 90%, 90 to 95%, 95 to 99%, and >99% of the histogram of simulated RADAM plots with a larger (19 ha) area; and plotted the results in the map of Pará state to visualize their spatial distribution (see the example of *Handroanthus* spp. in Fig. 2).

Furthermore, we obtained the identification of the forester in charge of each logging permit (97 professionals) and selected those with at least three licenses for one of the selected species. According to Brazilian regulations, forest management plans must have a forester in charge of the technical responsibility of operations. Then, we ranked the logging permits/RADAM plots ratio with the number of foresters as a means to evaluate the proportion of foresters in charge of logging permits with higher chances of fraud.

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/4/8/eaat1192/DC1

Fig. S1. Study sites in Pará state, eastern Amazon, Brazil.

Table S1. Commercial timber species used in the study and their associated characteristics.

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