LETTER

Examining protected area effectiveness in Sumatra: importance of regulations governing unprotected lands

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Abstract

Several studies suggest that protected areas conserve forests because deforestation rates are lower inside than outside protected area boundaries. Such benefits may be overestimated when deforestation rates within protected areas are contrasted with rates in lands where forest conversion is sanctioned. Here, we reexamine protected area performance by disentangling the effects of land use regulations surrounding the 110,000 km^2 protected area network in Sumatra, Indonesia.

We compared 1990–2000 deforestation rates across: (1) protected areas; (2) unprotected areas sanctioned for conversion; and (3) unprotected production areas where commercial logging is permitted but conversion is not. Deforestation rates were lower in protected areas than in conversion areas (Mean: −19.8%; 95% C.I.: −29.7—−10.0%; $P < 0.001$), but did not differ from production areas (Mean: −3.3%; 95% C.I.: −9.6—2.6%; $P = 0.273$).

The measured protection impact of Sumatran protected areas differs with land use regulations governing unprotected lands used for comparisons. If these regulations are not considered, protected areas will appear increasingly effective as larger unprotected forested areas are sanctioned for conversion and deforested. In the 1990s, production areas were as effective as protected areas at reducing deforestation. We discuss implications of these findings for carbon conservation.

Introduction

Protected areas have been the predominant biodiversity conservation approach for decades (Chape *et al.* 2005). An estimated 23% of the Earth's humid tropical forest biome is under some form of protected designation to conserve forest habitats and their biodiversity (UNEP 2007). The Convention on Biological Diversity's 2010 target to reduce the 2002 rate of biodiversity loss encouraged research into whether protected areas reduce deforestation (Brooks *et al.* 2009). To estimate the protection impact of forested protected areas, researchers have typically contrasted deforestation rates inside and outside protected area boundaries (DeFries *et al.* 2005; Nagendra 2008; Soares-Filho *et al.* 2010). Protection could be inferred effective if deforestation rates were lower in protected than in unprotected sites. But, the comparatively remote locations of many protected areas often overestimated protection impact (Joppa & Pfaff 2009). Studies controlled for this "high and far" bias using matching techniques or multiple linear regressions (Pfaff & Sanchez-Azofeifa 2004; Andam *et al.* 2008; Gaveau *et al.* 2009a; Pfaff *et al.* 2009). Even while controlling for this access-related bias, protected areas worldwide have been shown to reduce deforestation (Joppa & Pfaff 2010; Soares-Filho *et al.* 2010; Nelson & Chomitz 2011).

As with the access-related "high and far" bias, land use regulations in unprotected areas may affect the measured protection impact of protected areas. In unprotected areas, governments increasingly sanction forest conversion to industrial-scale activities (e.g., mining, plantations; Rudel *et al.* 2009). Such government approval increases access to these forest areas, facilitating industry-driven deforestation. Conversely, extensive areas of tropical forests outside protected areas are dedicated to commercial logging (Curran *et al.* 2004; Asner *et al.* 2005; Laporte *et al.* 2007), where forest conversion is prohibited.

Thus, just as deforestation rates within remote protected areas should not be compared with rates from less remote unprotected areas, deforestation in protected areas should not be compared with rates measured in unprotected areas sanctioned for conversion. Evaluating whether protected areas mitigate deforestation requires comparing deforestation rates in protected areas with rates measured in unprotected areas where land use regulations also prohibit forest conversion, such as production areas dedicated to commercial logging.

The Indonesian island of Sumatra (~440,000 km^2) provides an excellent test case for such analyses. Sumatra contains a network of protected areas spanning ~110,000 km^2, as well as ~114,000 km^2 allocated for timber production, where deforestation is prohibited, and ~214,000 km^2 sanctioned for conversion (MoF 2011). From 1985 to 1997, forest conversion to industrial-scale wood fiber and oil palm plantations (each >5,000 ha per license) contributed >32% of deforestation outside protected areas (Lewis & Tomich 2002).

Here, we examine whether Sumatran protected areas reduce deforestation. We compare deforestation rates among three land use categories: (1) protected areas, (2) unprotected areas sanctioned for conversion (conversion); and (3) unprotected areas where commercial logging is permitted but conversion is not (production).

Methods

Deforestation mapping

We mapped 1990–2000 deforestation in Sumatra (440,000 km^2) using 98 LANDSAT TM and ETM+ satellite images (Figure 1). Methods used to produce the deforestation map and assess its accuracy are described in Gaveau *et al.* (2009a). Here, "forest" refers to mixed dipterocarp stands; this class includes intact forests as well as forests degraded by logging. "Deforestation" is defined as a transition from forest to nonforest within the study time interval (1990–2000), with a ≥2 ha minimum mapping unit. Patches of deforestation <2 ha were excluded from the deforestation analysis presented here. We digitized 1990 and 2000 logging trails, visible in Landsat imagery (truck roads and skid trails, indicating mechanized logging). Areas ≤15 m of the logging trails were classified as "logging road," and were excluded from our analysis. Canopy gaps caused by logging (i.e., tree felling and log landings), created post-1990 in areas >15 m from the logging trails, and ≥2 ha in size, were considered "forest" if these areas had regrown to resemble the spectral signature of intact forests in 2000.

Across Sumatra's cloud-free forest cover, a subset of 1,264 square cells (25 km^2) representing 11% of total forest area in 1990, was used to compare deforestation rates between protected areas and nonprotected lands (Figure 1a). Deforestation area (1990–2000), extracted for each cell, is expressed as percentage of 1990 forest area (0–100%).

Land use regulations

Under Indonesia's 1990 National Spatial Plan (*Paduserasi*), forests were distributed among three broad land management zones: (1) protection, (2) production, and (3) conversion (Broich *et al.* 2011; MoF 2011). In the 1990s, the protection, production, and conversion zones of Sumatra extended ~110,000 km^2, ~114,000 km^2, and ~214,000 km^2, respectively. Each is discussed in turn.

(1) The protection zone (*Taman Nasional*, *Cagar Alam*, *Suaka Margasatwa*, *Taman Wisata*, *Taman Buru*, and *Hutan Lindung*) includes national parks, nature reserves, wildlife sanctuaries, recreational and hunting parks, and watershed protection reserves. Deforestation and logging are prohibited.
(2) The production zone (HP *Hutan Produksi <300 m asl,* and HPT *Hutan Produksi Terbatas* >300–500 m *asl*) comprises areas allocated for commercial logging, where deforestation is prohibited. However, because the Indonesian Ministry of Forestry defines wood fiber plantations as forests (Sasaki & Putz 2009), some production lands have been converted to industrial wood fiber plantations (HTI *Hutan Tanaman Industri*). To identify cells within this production zone sanctioned for conversion to wood fiber plantations, we visually inspected our database of Landsat images. Plantations were readily identified as large geometrically shaped clear-cut areas with distinctive homogeneous spectral signatures characteristic of monoculture stands (e.g., spp. *Acacia mangium*).
(3) The conversion zone (HPK *Hutan Produksi Konversi*, and *APL Areal Penggunaan Lain*) includes

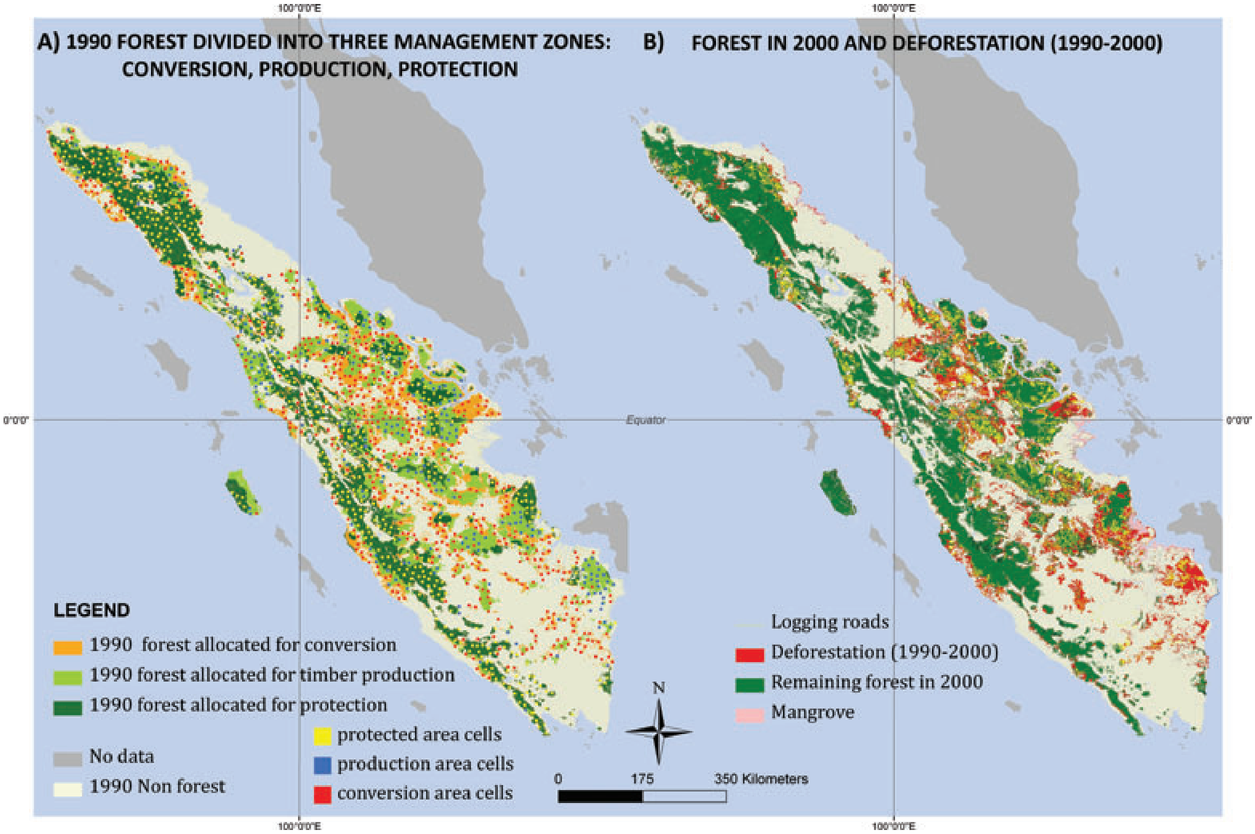

Figure 1 (a) Forest cover in 1990 for the islands of Sumatra and Siberut (total land area 440,000 km^2), across three management zones: (1) protection, (2) production, and (3) conversion. The sample of 1,264 square cells (25 km^2) used to evaluate protected area effectiveness is shown. There are: 463 protected cells (yellow), 238 production cells (blue), and 563 conversion cells (red, of which 103 lied in the production zone, but overlapped with wood fiber industrial plantations). (b) Remaining forests in 2000 and forest conversion from 1990 to 2000 (UTM projection, WGS84), with logging trials. The map in Panel B is available in GoogleEarth format (1:150,000) at http://sumatranforest.org/sumatranWide.php.

regions allocated to industrial plantations, smallholder agriculture, mining, urban areas, and government-sponsored transmigration settlements. Although permits are technically required to clear forests in this zone, government agencies typically exhibit de facto tolerance of deforestation without governmental permits.

We designated each square cell as: (1) protected, (2) production, or (3) conversion, using the following classification system:

(1) cells in the protection zone were classified as "protected" ($N = 463$);
(2) cells in the production zone but outside plantations were classified as "production" ($N = 238$);
(3) cells in the production zone but inside plantations were classified as "conversion" ($N = 103$); and
(4) cells in the conversion zone were classified as "conversion" ($N = 460$).

Controlling for bias in protected area location

To reduce any potential bias arising from the nonrandom geographic placement of land use regulations, especially remote and inaccessible protected areas, we used the statistical procedure propensity score matching. This procedure matched protected cells with unprotected cells most similar in geographic accessibility (i.e., slope, elevation, distance to forest edge, and distance to roads). We cross-checked propensity score matching results with conventional multiple linear regression, also known to effectively reduce potential biases (Rubin 1973; Rosenbaum 2005). Statistical methods are described in supporting information and in Gaveau *et al.* (2009a).

Results

Over 47% of the 440,000 km^2 study area was covered in intact forests in 1990 (Figure 1a). By 2000, forested area had decreased by 50,078 km^2, representing ~26% loss in forest cover (Figure 1b). The conversion zone lost 52% of its 1990 forest cover, although the production zone experienced 30% loss. Forest cover declined only 5% in the protection zone, in part because protected areas are comparatively remote and inaccessible (Gaveau *et al.* 2009a). Forest conversion to agricultural plantations in protected areas (oil palm, rubber, and wood fiber) was marginal. Logging trails in forested regions extended across 3,200 km^2 (∼49,000 km length), i.e., 6% of 1990–2000 deforestation. This area was excluded from our analysis of deforestation.

Using propensity score matching without considering land use regulations in unprotected areas, mean deforestation rate was significantly lower in protected than unprotected areas (−11.1%; 95% C.I.: −16.7—−5.4%; $P < 0.001$; Table 1). Incorporating land use regulations revealed a mean deforestation rate nearly two-fold lower in protected than conversion areas (−19.8%; 95% C.I.: −29.7—−10.0%; $P < 0.001$; Table 1). Most importantly, deforestation rates in protected and production areas did not differ significantly (−3.3%; 95% C.I.: −9.6%—2.6%; $P = 0.273$; Table 1).

Our protected area category included 58% watershed protection forest reserves (*Hutan Lindung*, HL), areas that receive neither funds nor are actively managed by governmental agencies. By grouping these HL reserves with protected areas that have conservation and management resources (i.e., national parks, nature reserves, and wildlife sanctuaries), we potentially diluted the protection impact of "managed" protected areas. However, when HL reserves were excluded from the protected area category, the mean deforestation rate within remaining "managed" protected areas did not differ significantly from deforestation rates detected in production areas (−2.6%; 95% C.I.: −13.9%—8.8%; $P = 0.65$; Table 1).

Propensity score matching balanced confounding variables of inaccessibility across protected and unprotected areas (Table S1). Compared to the multiple linear regression model, propensity score matching estimated greater differences in mean deforestation rate in three of the four land use comparisons. Both methods exhibited agreement in quantity, confidence interval, and sign variations across all four comparisons (Table 1), indicating robust findings. Detailed multiple linear regression results are provided in Tables S2–S5.

Discussion

The protection impact of Sumatran protected areas, measured by contrasting deforestation rates inside and outside protected area boundaries, differs with land use regulations in unprotected forests. From 1990 to 2000, protection impact was six-fold greater when protected areas were compared to lands sanctioned for conversion than when compared to lands managed for timber production. Protected areas effectively prevented government-sanctioned deforestation; forest conversion to large-scale agricultural plantations (i.e., oil palm, rubber, or wood fiber) was marginal within protected area boundaries. Yet, protected areas were no more effective at preventing deforestation than forests managed for timber production. Our findings corroborate evidence from throughout the tropics that suggests deforestation persists within protected areas when strong socioeconomic drivers of deforestation are coupled with insufficient management resources (van Schaik *et al.* 1997; Brandon *et al.* 1998; Curran *et al.* 2004; Naughton-Treves *et al.* 2006; Gaveau *et al.* 2009b; Leverington *et al.* 2010; Verissimo *et al.* 2011).

Encouragingly, our results also reveal that forests managed for timber production were as effective as protected areas at preventing deforestation during the 1990s. This finding indicates that logging concessions have been a relatively effective means of maintaining forest cover in Sumatra over decadal timescales. This observation comes with two major caveats. First, logging concessions are officially slated for sustainable, selective logging. However to compensate for the loss of logging revenue following years of overharvesting that depleted commercial timber stocks by the late 1980s, in ∼1990 Indonesia's Ministry of Forestry began issuing permits to convert some production forests into industrial wood fiber plantations (Kartodiharjo & Supriono 2000). In contrast, forest conversion to industrial plantations was not allowed extensively inside protected areas. Thus, compared to production forests, protected areas have been less vulnerable to changes in land use status that might encourage deforestation. Second, our analysis did not measure whether protected areas reduced forest degradation caused by logging. Yet, degradation is assumed to be more prevalent in production forest areas where logging is permitted than within protected areas where logging is prohibited. Although forest degradation has relatively lower impacts on the overall maintenance of biodiversity than deforestation (Woodcock *et al.* 2001; Meijaard & Sheil 2008; Edwards *et al.* 2011; Gibson *et al.* 2011) it remains an important anthropogenic disturbance that affects large tropical forest areas (Broadbent *et al.* 2008; Asner *et al.* 2009). Logging has been shown to increase fire vulnerability (Nepstad *et al.* 1999; Siegert *et al.* 2001), and to impart major effects on canopy tree regeneration and vertebrates (Curran & Leighton 2000; Curran & Webb 2000). Because they guard against forest degradation as well as deforestation, protected areas therefore remain central to forest conservation efforts.

Table 1 Comparison of mean differences in percent deforestation rates from 1990 to 2000. These values are expressed in percent losses per 1990 forest cover per cell, with values that ranged from 0% to 100% on a continuous scale. Confidence intervals are derived from propensity score matching and multiple linear regression. The mean difference is between: (1) protected and unprotected cells (conversion and production combined); (2) protected and conversion cells; (3) protected and production cells; and (4) managed protected cells (i.e., national parks and nature reserves) and production cells. Both propensity score matching and multiple linear regression analyses indicate considerable agreement across all four comparisons

	Protected versus unprotected	Protected versus conversion	Protected versus production	Managed protected versus production
Propensity score matching				
Mean difference (%)	−11.1	−19.8	−3.3	−2.6
(95% C.I.)	(−16.7—−5.4)	(−29.7—−10.0)	(−9.6—2.6)	(−13.9—8.8)
Significance	0.000	0.000	0.273	0.65
Wilcoxon test	0.000	0.000	0.245	0.668
N_{PA} vs. N_{nonPA}	151 vs. 151	71 vs. 71	80 vs. 80	36 vs. 36
Multiple linear regression				
Mean difference (%)	−9.7	−23.9	−2.4	−0.62
(95% C.I.)	−16.1—−3.3	−28.9—−19.0	−6.1—1.3	−4.28—5.5
Significance	0.000	0.000	0.209	0.804
N_{PA} vs. N_{nonPA}	463 vs. 801	463 vs. 563	463 vs. 238	233 vs. 238

These results address to whether existing protected areas qualify to be included under Reduced Emissions from Deforestation and Degradation (REDD+) initiatives. If existing protected areas already appear to be effective in mitigating deforestation, they may not confer emissions reductions ("additionality") under REDD+ (Nepstad *et al.* 2006; Andam *et al.* 2008; Gaveau *et al.* 2009a; Joppa & Pfaff 2010; Soares-Filho *et al.* 2010; Nelson & Chomitz 2011). Our findings suggest that in the 1990s Sumatran protected areas were no more effective at preventing deforestation than production forests that are eligible for REDD+ investments. Therefore, existing Sumatran protected areas appear to meet conditions for inclusion in Indonesia's national and subnational REDD+ programs, potentially providing additional, merit-based funding to support protected area management.

As the global protected area network expands to include reserves dedicated to carbon sequestration (Wertz-Kanounnikov & Kongphan-apirak 2009; Paoli *et al.* 2010), evaluations of protected area efficacy must be refined. To estimate the impact of forested protected areas, researchers already control for a suite of biophysical access-related variables (e.g., topography, distance to roads, and settlements). Here, we show that controlling for government-mediated access, in the form of land use regulations, is also critical. If these regulations are not considered, protected areas will appear increasingly effective as larger unprotected forested areas are sanctioned for conversion and deforested. As government-sanctioned, industrial agriculture continues to expand across the tropics (Defries *et al.* 2010), this methodological approach will be an essential component of land use change research evaluating the success of both protected areas and REDD+ initiatives.

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Supporting Information

Additional Supporting Information may be found in the online version of this article, including Supplementary Methods and References.

Table S1: Results of *t*- and Kolmogorov–Smirnov (KS) tests before and after matching for the main island of Sumatra and the smaller island of Siberut during 1990–2000.

Table S2: Results of the linear regression model for protected versus unprotected (conversion and production), with percent deforestation is the response variable.

Table S3: Results of the linear regression model for protected versus conversion, with percent deforestation is the response variable.

Table S4: Results of the linear regression model for protected versus production, with percent deforestation is the response variable.

Table S5: Results of the linear regression model for managed protected (national parks, nature reserves, and wildlife sanctuaries) versus production, with percent deforestation is the response variable.

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