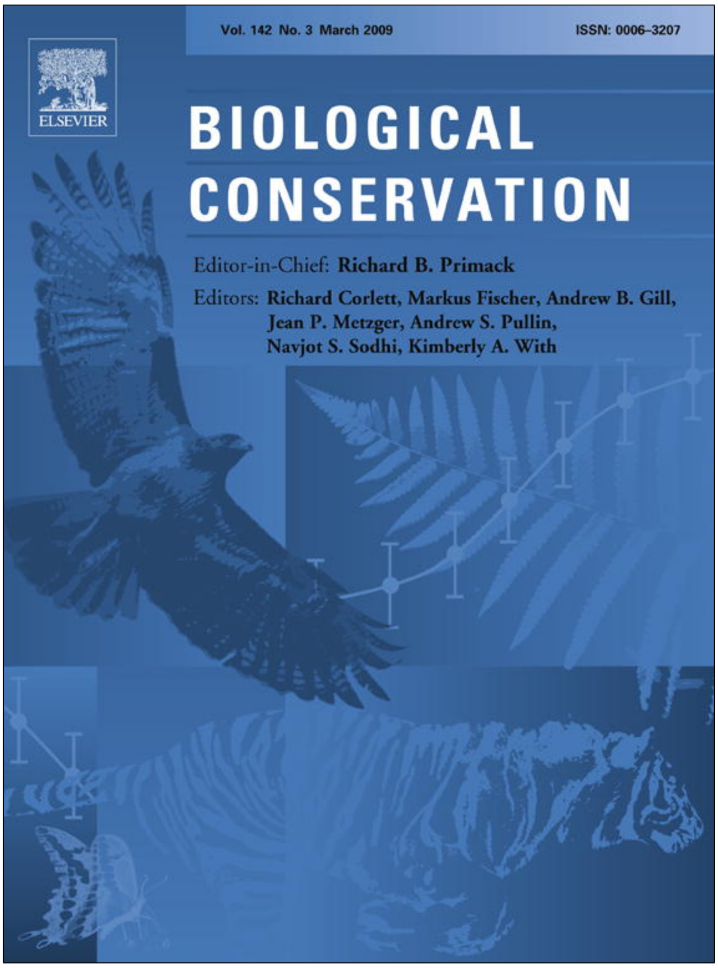
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Three decades of deforestation in southwest Sumatra: Effects of coffee prices, law enforcement and rural poverty

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ABSTRACT

In situ conservation of tropical forests often requires restricting human use and occupancy within protected areas by enforcing regulations. However, law enforcement interventions that seek to prevent deforestation rarely have been evaluated. Conservationists increasingly recognize the need to measure the effectiveness of their interventions, using an indicator of biodiversity change, such as rate of deforestation, and a counterfactual approach that addresses a fundamental question: what would have happened had there been no intervention? This study examines how law enforcement can mitigate habitat loss from small-holder coffee growing by comparing 34 years of empirical data on deforestation rates and coffee prices across a zone of high law enforcement and a zone of low law enforcement using satellite imagery, ecological data, interviews, and GIS modeling..

In the early 1980s strong law enforcement efforts were found to reduce deforestation inside Bukit Barisan Selatan National Park (BBSNP), southwest Sumatra. However, law enforcement efforts were weak in remote areas of BBSNP, where high coffee prices spurred rapid deforestation. Furthermore, law enforcement efforts were reversed by the 1997–1998 Asian economic crisis, the fall of the national president, and by new regulations surrounding regional autonomy. These findings indicate that law enforcement is critical but insufficient alone. They also highlight that rising costs of agricultural commodities can be detrimental to tropical forests and their associated biodiversity. In the long run one must act to decrease the incentives for coffee cultivation. A multi-faceted strategy that includes law enforcement and incentives to reduce poverty around PAs is proposed.

1. Introduction

Tropical forests are disappearing at an estimated rate of 58,000 $km^2\ yr^{-1}$ (Achard et al., 2002). The international community faces the urgent task to reduce tropical deforestation as one of a suite of measures to reduce global warming and maintain biological diversity (UNFCCC, 2007). An approach commonly followed by governments to prevent tropical

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deforestation has been to establish Protected Areas (PAs), and an estimated 23% of the Earth's humid tropical forest biome is now under protection (UNEP, 2007). However, many PAs have lost some or all of their natural habitats through conversion to agriculture (Curran et al., 2004; DeFries et al., 2005; Southworth et al., 2006) casting doubts as whether PAs are effective at conserving their biodiversity. Equally, some reviews have suggested that tropical PAs have been more effective at stemming habitat loss than is commonly thought (Bruner et al., 2001; Naughton-Treves et al., 2005). Equally, like many other interventions in conservation, the effectiveness of tropical PAs has often not been evaluated rigorously. Therefore, many now recognize the need to measure the effectiveness of conservation strategies, using an indicator of biodiversity change, such as rate of deforestation, coupled with a counterfactual approach (Ferraro and Pattanayak, 2006) that addresses the fundamental question: what would have happened had there been no intervention?

In the 1980s, international development agencies such as the World Bank favored law enforcement inside tropical PAs as a way to reduce deforestation (World Bank, 1994). However, others believe that growing poverty around PAs places constraints on the protection of tropical rainforests, and that a key component to conservation success lies in poverty alleviation (Adams et al., 2004). Such views underscore the belief that poverty reduction and tropical forest conservation are strongly interconnected (Robinson, 2006). But, the link between poverty and deforestation has not been convincingly quantified because of the complexity in which processes of deforestation operate (Lambin et al., 2003), while conservation-with-development projects that have sought to reduce biodiversity loss through development have not generally succeeded (Adams et al., 2004; Linkie et al., 2008). In contrast, several studies of valuable flagship species such as elephants and rhinos support the contention that, when adequately resourced and funded, law enforcement is effective (Hilborn et al., 2006; Jachmann and Billiouw, 1997; Keane et al., 2008). What has not been well evaluated is how law enforcement can prevent habitat loss in tropical forest PAs. This study examines whether law enforcement has helped to prevent loss of natural habitat and conserve tropical forests in one World Heritage Indonesian national park.

Throughout the 1970s, the Indonesian government generated cash for economic development by logging its vast forest resources, in line with the post-colonial development agenda of industrialized nations (Pretzsch, 2005). Furthermore, little emphasis was placed on preventing illegal logging and agricultural encroachments into PAs. However, three events caused Indonesia to alter its conservation policies in the early 1980s and to lay the foundation for Indonesia's current national parks system. These were the UNDP/FAO National Parks Development Project (De Wulf et al., 1981), the promulgation of the first Environmental Management Act (EMA) (Law of 1982, State Gazette 1982, no 3215) and the third World Parks Congress (WPC) held in Bali in 1982 (Sakumoto, 1999). Following this policy change, the Indonesian government applied a strong law enforcement model within many of Indonesia's protected areas to safeguard forests. This study explores to what extent this strategy, established jointly by the government of Indonesia and by international institutions, has succeeded for the UNESCO-listed World Heritage Site of Bukit Barisan Selatan National Park (BBSNP), Sumatra, and discusses some of the policy implications for balancing law enforcement and incentives that might reduce poverty around PAs.

A previous study suggested that high international prices for coffee increased rates of deforestation in BBSNP, while low prices decreased them (O'Brien and Kinnaird, 2003). Therefore, this study tested whether low coffee prices confounded measurements of law enforcement effectiveness, and to what extent law enforcement has performed against the competing incentive of rising coffee prices. In the current global context of rising agricultural commodity prices understanding the effects of price changes on farmers' behavior and the consequences for forest conservation is vital. In addition, some studies have shown that the Asian economic crisis of 1997–1998 has impeded conservation efforts in Indonesia (Curran et al., 2004; Jepson et al., 2001), so this study also explored to what extent law enforcement has performed post-Asian crisis.

These questions were addressed by comparing fluctuations in tropical deforestation over time (1972–2006) across a 'treatment' zone of high law enforcement and a 'control' zone of low law enforcement. The control and treatment zones were identified using ecological field data, interviews, and GIS modeling. The time-series data on deforestation rates were measured using satellite imagery. Deflated coffee prices were calculated. These data were confronted for both zones.

2. Study area

The study area spans 11700 km^2 of land lying within Indonesia's main robusta coffee growing region (Fig. 1). Over half (6928 km^2) of the entire study area was covered in natural forest in 1972 (Gaveau et al., 2007). The study area includes the 3245 km^2 Bukit Barisan Selatan National Park (BBSNP) which was initially established in 1934 as a nature reserve by the government of the Dutch East-Indies, and later upgraded to the status of national park during WPC Bali in 1982 (De Wulf et al., 1981). Until the 1970s, the area within the now BBSNP was preserved from anthropogenic deforestation by its remoteness, and by the generally low population density across the wider region. But, in 1977 the record high international price of robusta coffee triggered unplanned mass migration to the mountainous areas of southwest Sumatra, and initiated a major deforestation front on the eastern fringe of BBSNP, involving an estimated 100,000 immigrants primarily originating from Java (Benoit et al., 1989; Scholz, 1983). Over the last 34 years agricultural expansion for low-grade robusta coffee production by smallholders has been the dominant driver of deforestation in and around BBSNP (Benoit et al., 1989; De Wulf et al., 1981; Scholz, 1983; Suyanto 2007). An estimated >85% of the forest area converted to agriculture inside BBSNP had been planted in coffee plantations in 2005 (Gaveau and Wandono, 2005). An estimated 20,000 metric tons of coffee were produced inside BBSNP in 2006, representing circa 4% of Indonesia's overall annual robusta coffee production (WWF, 2007).

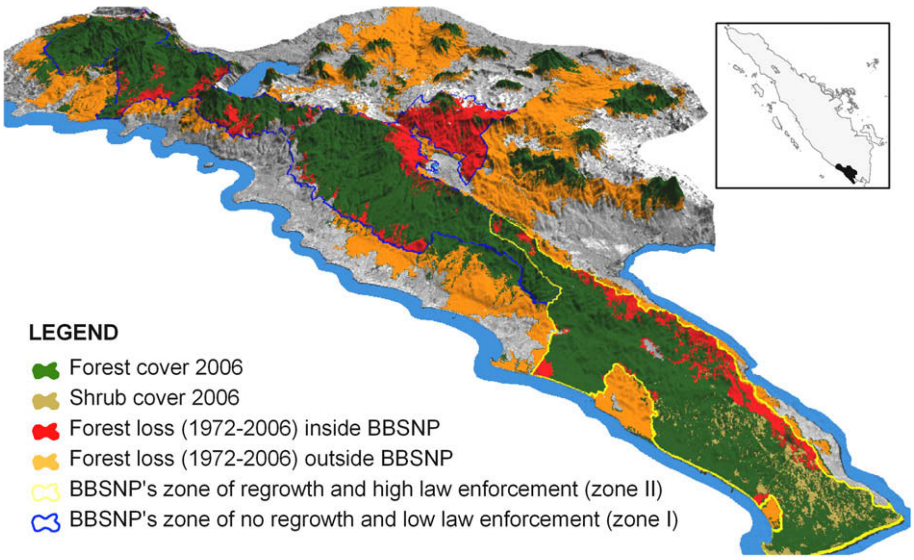

Fig. 1 – Cumulative forest loss inside Bukit Barisan Selatan National Park BBSNP (red) and in surrounding areas (orange) from 1972 until 2006 within the 11,700 km^2 study area. The insert shows the location of the study area (black) in Sumatra. The boundary of BBSNP's zone of no re-growth (Zone I) is in blue. The boundary of BBSNP's zone of re-growth (Zone II) is in yellow. The data are overlaid on a Digital Elevation Model (DEM) and LANDSAT satellite imagery to generate a three-dimensional grey color composite background. (For interpretation of the references in colour in this figure legend, the reader is referred to the web version of this article.)

3. Methods

3.1. *Time-series of deforestation rates*

Detailed processing methods for generating forest cover maps and assessing their accuracy have been described previously (Gaveau et al., 2007). Briefly, empirical data spanning 34 years have been generated on deforestation rates inside BBSNP. A total of 21 LANDSAT satellite images were processed to calculate the loss of forest cover across the entire study area of 11,700 km^2, during the period 1972–2006. An eleven-date deforestation map was generated inside BBSNP for the years 1972, 1976, 1978, 1982, 1985, 1989, 1994, 1997, 2000, 2002, and 2006. The imagery for these years had negligible cloud cover (<3.5%), and allowed the calculation of deforestation rates over ten, almost equally spaced, time intervals. The same time-series could not be mapped consistently for the entire study area because of persistent cloud cover in some areas outside BBSNP.

Areas of forest, non-forest, water (oceans, lakes and large rivers), cloud and deforestation were mapped. 'Forest' refers to old-growth forest (canopy cover >50%), either undisturbed or partially degraded by selective logging or thinning. 'Deforestation' is defined as the complete removal of forest cover. 'Non-forest' comprises human settlements, grasslands, re-growth areas (shrubs and young forest trees), paddy fields, and tree crops. Coffee gardens comprise the predominant tree crops, which also include pepper, cinnamon, coconut and oil palm plantations, orchards and an old-growth traditionally managed agro-forest (Michon and Foresta, 1992).

Four steps were followed to generate the eleven-date deforestation output. First, the imagery was registered to a geo-referenced dataset using global positioning system, and second-order polynomial co-registration technique (Schowengerdt, 1997), thus ensuring high positioning accuracy. Second, the imagery was classified as a temporal progression of forest change to identify areas of deforestation using a gaussian maximum likelihood classification (MLC) algorithm (Schowengerdt, 1997). Third, additional measures were taken to ensure high accuracy of the time-series, including (a) filtering the final classification results to exclude areas <1 ha, and (b) manually editing complex areas such as those obscured by haze or in steep topography, where the classification algorithm was most likely to produce misclassification errors, but where a trained remote sensing analyst still could visually interpret the imagery. Finally, the accuracy of forest classification was assessed for two forest cover maps in this time-series, and these were found to have high accuracy (⩾95%) (Gaveau et al., 2007).

3.2. *Coffee prices time-series*

Time-series statistics on annual international (in US dollars) and local (in Indonesian Rupiah, Rp) robusta coffee prices were assembled from the International Coffee Organization (ICO) indicator price reports and from the Indonesian Bureau of Statistics, respectively (Fig. 2). The local price time-series was deflated by the southern Sumatra Consumer Price Index (CPI, 2006 = 100) to account for the growth of local consumer prices and agricultural input prices over time.

3.3. *Defining zones of high and low law enforcement*

Zones of high and low law enforcement inside BBSNP were identified based on: (i) ecological data; (ii) interviews with farmers and BBSNP staff; and (iii) GIS modeling.

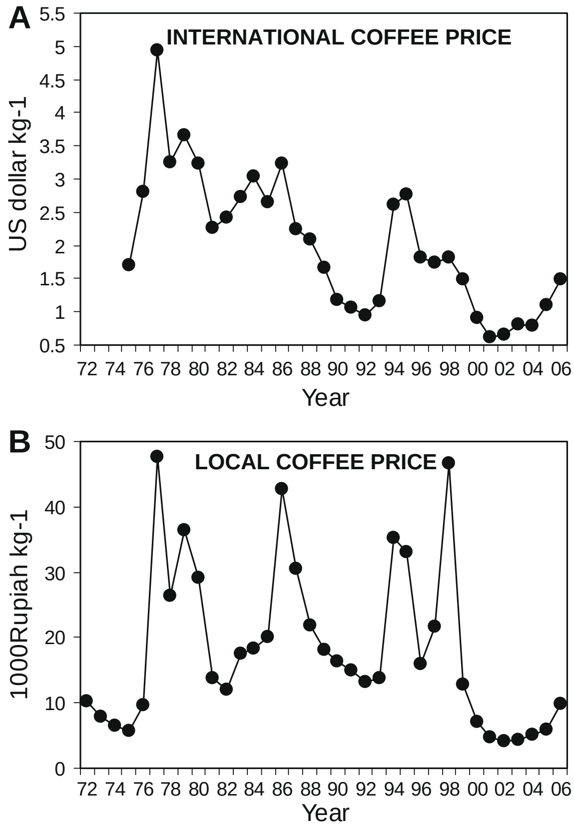

Fig. 2 – (A) Time series of annual international robusta coffee (ICO indicator) prices. (B) Time series of annual local robusta coffee (farmgate) prices. International and local coffee prices are correlated (Pearson's $r = 0.745$, $P < 0.001$).

3.3.1. *Ecological data*

A previous study had allowed encroachments into BBSNP to be grouped into 'active' or 'inactive', based on whether they had expanded in area since BBSNP was established (Gaveau et al., 2007). Field surveys revealed extensive re-growth over previously cleared forest areas in 'inactive' encroachments, but not in 'active' encroachments (Gaveau et al., 2007). There was no spatial overlap between 'active' encroachments, all of which were in the northern section of BBSNP, and 'inactive' encroachments, all found in the southern section of BBSNP. In turn, this allowed BBSNP to be sub-divided into two distinct zones, of no re-growth (Zone I = 2455 km^2) and of re-growth (Zone II = 790 km^2) (Fig. 1).

If law enforcement has caused re-growth, while park staff focused enforcement efforts on Zone II because Zone I is too remote from the Park HQ, Zone I may be assigned the zone of low law enforcement, while Zone II may be assigned the zone of high law enforcement. Conversely, if remoteness rather than law enforcement has caused re-growth in Zone II because farmers preferably convert forests in Zone I, geographic accessibility may confound the assessment of law enforcement. These questions were further tested using interviews and GIS modeling.

3.3.2. *Interviews*

The HQ office for BBSNP has not recorded quantitative records of past law enforcement efforts, so consistent measurements are lacking such as patrolling and eviction rates over time and across space. Therefore, three long-term staff who had worked in BBSNP since 1982 were interviewed to determine when and where law enforcement operations had taken place in BBSNP. The interview results were cross-checked the results with independent interviews of 1384 farmers, among whom the survey attempted to locate as many evicted farmers as possible. Given that the whereabouts of evicted farmers were not known in advance, the most systematic sampling strategy proved to be conducting interviews from north to south along the BBSNP border. For those farmers with a history of eviction, when and where the eviction had occurred was determined.

3.3.3. *Modeling spatial accessibility*

Accessibility into BBSNP was modeled spatially as travel times rather than as straight-line distances, to simulate the likelihood of farmers and BBSNP staff traveling along the path of least resistance (Verburg et al., 2004) either from their settlements or from their HQ office to forest locations inside BBSNP. Accessibility was treated as a static variable because roads and settlements have not changed sufficiently since the early 1980s across the zones. Slope-dependent off-road walking speeds, calculated for a complex agricultural landscape at the forest margin in the Philippines were used to generate a friction map from NASA's SRTM DEM-derived slope map (Rabus et al., 2003). One friction map was used to generate travel times from known human settlements in early 1980s to BBSNP, and to test whether Zone II was less accessible to farmers than Zone I. Subsequently, a car and a boat speed (20 $km\ h^{-1}$) were added to a second friction map because BBSNP staff traveled by boat or car to reach BBSNP, but then patrolled on foot within BBSNP (ParkOffice, 1982–2004). This second friction map was used to generate travel times from the BBSNP HQ office to BBSNP, and test whether Zone II has remained more accessible to BBSNP staff than Zone I. Mann-Whitney U tests were used to compare the mean travel times to Zone I and to Zone II from human settlements and from the BBSNP HQ office, respectively. Mean travel time values were extracted for 300 randomly selected points on Zone I as having been cleared and 100 randomly selected points on Zone II.

3.4. *Analysis of time series data*

Time-series of deforestation rates were calculated separately for Zones I and II. Any longitudinal differences in deforestation rates were predicted to arise from law enforcement efforts. A linear regression tested this prediction, incorporating the re-growth in Zone II, and fluctuations in local and international coffee prices. The deforestation caused by ENSO-related 1997–1998 wild fires inside BBSNP (~15–20 km^2) (Adeney et al., 2006) was excluded from the analysis, as this would bias the measurement of coffee-related anthropogenic deforestation. Deforestation rates in Zones I and II were differentiated by assigning a value of 0 to Zone I and a value of 1 to Zone II. Maximum values for coffee prices are more relevant for predicting farmer behavior than average values, because high coffee prices create expectations about future prices (Angelsen, Personal communication). Therefore, maximum coffee prices per time interval were entered as continuous covariates in the model, first using local prices and then repeating the analysis for international coffee prices.

4. Results

The entire study area lost 3595 km^2 of the original forest cover of 6928 km^2 that remained in 1972, representing a 52% loss from 1972 to 2006. By contrast, forest cover inside BBSNP reduced by 637 km^2 from anthropogenic activities, representing a 21% loss of original 1972 forest cover, at an average rate of 0.62% yr^{-1} (Fig. 1). Meanwhile, BBSNP's southern peninsular (Zone II) experienced substantial re-growth, estimated to cover circa 100 km^2 over forest areas cleared since 1972 (Gaveau et al., 2007).

A linear regression model showed that local coffee prices and the fixed factor for Zones I and II both closely predicted deforestation rates inside BBSNP ($F_{2,20} = 7.438$, $P = 0.005$, $r^2 = 0.467$) (Table 1). Thus, higher local coffee prices spurred faster deforestation ($\beta = 0.029$, $F_{1,20} = 5.811$, $P = 0.028$), a periodic effect that was especially noticeable in Zone I (Fig. 3A and B). Whilst international coffee prices strongly correlated (Pearson's $r = 0.745$, $P < 0.001$) with local prices (Fig. 2), international prices did not explain deforestation rates inside BBSNP ($\beta = 266.7$, $F_{1,20} = 2.485$, $P = 0.133$). This apparent paradox will be discussed below.

Deforestation rates were lower in Zone II than in Zone I ($\beta = -1130.3$, $F_{1,20} = 9.066$, $P = 0.008$). The lower deforestation in Zone II was particularly strong between 1982 and 2000, when deforestation rates reduced to almost nil (Fig. 3C). However, geographic accessibility does not appear to explain the observed reduction in deforestation, nor the subsequent re-growth in Zone II. Indeed, Zone II, with a mean ± SD travel time for farmers of 3.85 ± 2.28 h is, on average, ~2.4 times (Mann Whitney U test: $Z = -11.27$, $P < 0.001$) less remote than Zone I with a mean travel time for farmers of 9.27 ± 4.35 h (Fig. 4A). The comparative framework, highlighting the main differences between Zone I and II is in Table 2.

Three long-term BBSNP staff, each with >24 years service, reported conducting only one intensive, but protracted eviction campaign inside BBSNP, during the period 1982–1985. These staff claimed to have patrolled Zone II extensively, evicted all illegal farmers and removed at least 1000 households from BBSNP's southern peninsular, in collaboration with the local police and army. Furthermore, long-term BBSNP staff claimed not to have intensively patrolled Zone I, on average ~ 3.5 times more remote (Mann Whitney U test: $Z = -14.9$, $P < 0.001$) from BBSNP HQ, with a staff travel time of 22.45 ± 7.37 h, than Zone II, with a travel time of 6.48 ± 2.68 hr (Fig. 4B). Among 1384 farmers interviewed along BBSNP boundary, only 58 farmers claimed to have been previously evicted, and >97% of recorded evictions occurred inside Zone II from 1982–1987. The farmers' interviews corroborate the reports of BBSNP long-term staff that intensive law enforcement efforts focused on Zone II in the early 1980s. These observations support assigning Zone I as low law enforcement and Zone II as high law enforcement.

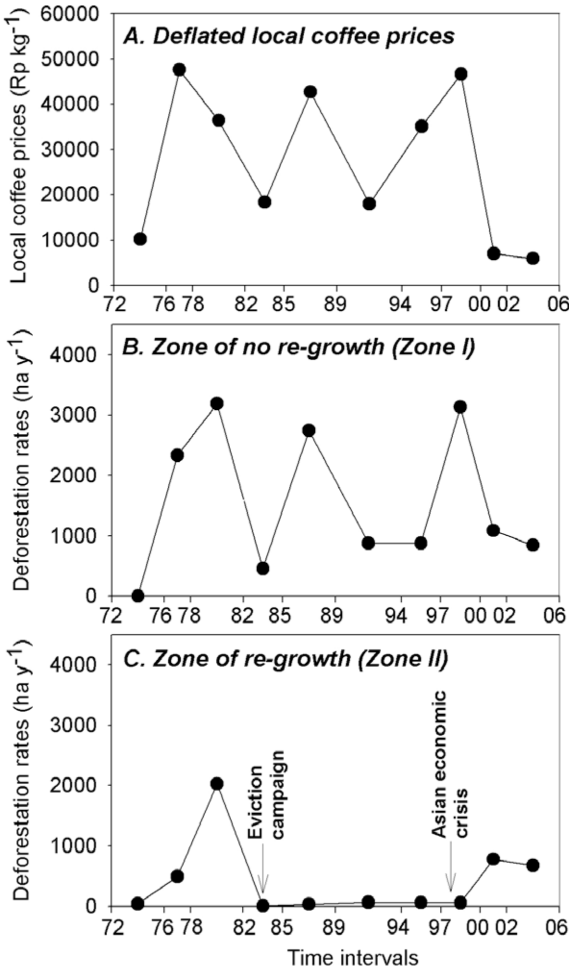

Fig. 3 – Time-series showing (A) deflated (CPI, 2006 = 100) maximum annual local coffee prices, (B) deforestation rates inside BBSNP's zone of no re-growth, and (C) deforestation rates inside BBSNP's zone of re-growth (since year 2000, deforestation rates in Zone II include deforestation of regrowth).

Table 1 – Linear regression model showing the effects of local coffee prices and the fixed factor for Zones I and II on predicting deforestation rates inside BBSNP.

Variables	Coefficients	Std. error	Significance
Local coffee price	0.029	0.012	0.028
Zone II (re-growth zone)	−1130.30	375.4	0.008
Constant	785.78	414.7	0.075
$R^2 = 0.467$, $P = 0.005$			

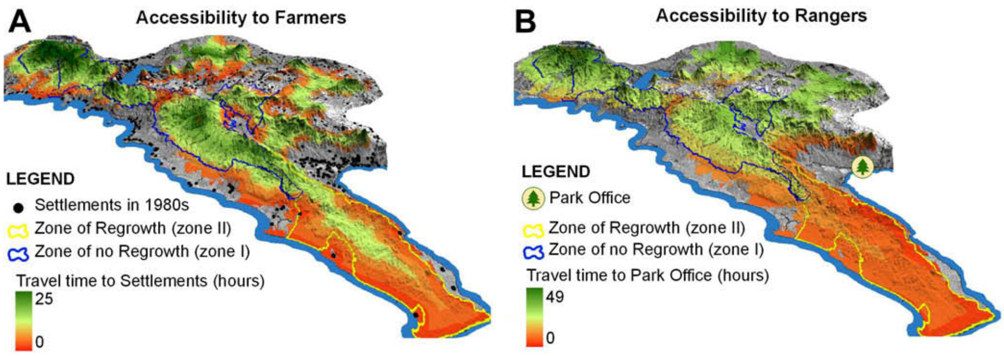

Fig. 4 – Travel times in hours taken (A) for farmers to travel from settlements, and (B) for rangers to travel from BBSNP HQ, to a forest location inside BBSNP. The most accessible forest areas are shown in red and the least accessible in dark green. Grey areas are areas of non-forest in 1972.

Table 2 – Comparative framework, highlighting the main differences between zones I and II.

Zone I (low law enforcement)	Zone II (high law enforcement)
Lies in northern BBSNP	Lies in southern BBSNP
Contains 'active' encroachments	Contains 'inactive' encroachments
Experienced little re-growth	Experienced extensive re-growth
Accessibility to farmers: 9.27 ± 4.35 h	Accessibility to farmers: 3.85 ± 2.28 h
Accessibility to rangers: 22.45 ± 7.37 h	Accessibility to rangers: 6.48 ± 2.68 h
Rangers have not patrolled extensively during 1982–1985.	Rangers have patrolled extensively during 1982–1985
<3% Interviewed farmers were evicted from zone I during 1982–1987	>97% Interviewed farmers were evicted from zone II during 1982–1987

The 1982–1985 period of law enforcement also witnessed low local coffee prices (Figs. 2 and 3A). This price decline provoked a reduction in deforestation rates throughout BBSNP, including in Zone I, the zone of low law enforcement effort (Fig. 3). However, deforestation rates in Zone I increased again during subsequent peak price years (Fig. 3B), but remained low in Zone II until 2000 (Fig. 3C). Hence, the 1982–1985 law enforcement intervention had a lasting effect, and helped contain deforestation during peak price years, some 15–20 years later (Fig. 3C). Therefore, law enforcement efforts appear to have successfully curbed coffee-related deforestation inside Zone II.

Following the Asian financial crisis of 1997–1998, the fall of President Suharto in 1998 and regional autonomy in 2000, deforestation rates in Zone II increased 18-fold, from <58 ha yr^{-1} during 18 consecutive years from 1982–2000, to 1000 ha yr^{-1} in 2000–2002, despite low prices for coffee (Fig. 3A and C).

5. Discussion

The importance of law enforcement in maintaining the integrity of PAs is well recognized, especially through studies of flagship species like rhinos, elephants and buffalos (Hilborn et al., 2006; Jachmann and Billiouw, 1997; Keane et al., 2008; Leader-Williams et al., 1990). This study is unusual in examining how law enforcement can mitigate coffee-induced tropical deforestation using a long time series on rates of deforestation as a measure of success coupled with a counterfactual approach that addresses the fundamental question: what would have happened had there been no intervention? In contrast to a previous study carried out in the same area (O'Brien and Kinnaird, 2003), the main findings are that local rather international coffee prices drive deforestation in BBSNP, Sumatra, and that coffee-related deforestation is successfully reduced with active law enforcement.

To a large extent currency devaluation explains why local rather than international prices drive deforestation in BBSNP. The Indonesian Rupiah (Rp.) decreased in value against the US dollar from Rp. 2400 in July 1997 to around Rp. 16000–17000 in July 1998, following the Asian financial crisis (Sunderlin et al., 2001). This sharp devaluation raised local coffee prices to a record high in 1998, while international coffee prices remained low (Fig. 2). This sudden increase in local coffee prices attracted new migrants to the area, while many non-farmers who saw their purchasing power decrease turned to part-time farming to generate cash (Gerard and Ruf, 2001). Overall, these results indicate that high producer prices for agricultural outputs accelerate deforestation because farmers who grow export cash crops act to maximize profits (Angelsen, 1999), and highlight that rising costs of agricultural commodities are likely to be detrimental to tropical forests and their associated biodiversity. These results come with some caveats, however. Ewers et al. (2008) found no statistical evidence that the prices of soy bean and beef had caused variations in deforestation rates in the Brazilian Amazon. This reflects the fact that many ongoing processes, acting in concert, combine to drive temporal variation in the annual deforestation rates in this part of the world. However, the compilation of time-series at finer spatial scales provides an alternative avenue for increasing the power of time-series analysis (Ewers et al., 2008). This local-scale study has controlled for ENSO-related 1997–1998 wildlife fires, in an area where coffee-related deforestation has been the dominant driver of deforestation (Benoit et al., 1989; De Wulf et al., 1981; Scholz, 1983; Suyanto, 2007). Therefore, despite statistical issues in using linear regression in time-series analysis (Ewers et al., 2008), the correlation found in this study between deforestation rates and local coffee prices is considered robust because it operates on a local scale.

The strong emphasis placed on law enforcement in the early 1980s following the creation of BBSNP greatly reduced deforestation in the southern peninsular of BBSNP, and subsequently enabled extensive forest re-growth. This result suggests that law enforcement is necessary to safeguard the integrity of BBSNP from migrant farmers who would otherwise clear forest to grow coffee, mirroring other studies suggesting that law enforcement interventions are also necessary to protect valuable species (Bulte and van Kooten, 1999; Hilborn et al., 2006; Keane et al., 2008; Kramer et al., 1997; Leader-Williams et al., 1990; Struhsaker et al., 2005; Terborgh, 1999). Furthermore, this study shows that the effects of strong law enforcement can persist for several years after law enforcement activities have ended, as with claims made for large mammals (Neumann, 2001). However, the effects of law enforcement have waned since the fall of President Suharto in 1998 and with the implementation of regional autonomy in 2000 (Curran et al., 2004). Since 1998, national park budgets have been reduced and patrols declined (ParkOffice, 1982–2004). Equally, the newly democratically elected local and national Indonesian governments have deemed evictions from strict PAs to be morally unjust. Equally, with the implementation of regional autonomy in 2000, local governments have shown little interest in biodiversity conservation because national parks fall under the jurisdiction of the national government and provide few economic returns locally (Levang et al., 2007), which has weakened collaboration between BBSNP staff and local authorities. In this context, illegal coffee farmers have become more defiant, and some have taken advantage of recent political changes to return to sites from which they were evicted. As a result, boundary conflicts between farmers and BBSNP authorities have increased (ParkOffice, 1982–2004). Furthermore, most rangers live locally with their families, so any forceful intervention inside BBSNP is liable to retaliation. Without support from local authorities, rangers are reluctant to jeopardize their family's welfare in return for a low salary. Therefore, BBSNP's once strong law enforcement regime of the early 1980s has been weakened by changing economic and political circumstances. A major weakness of basing conservation success on strong law enforcement is that any sudden major political or economic disruption can negate long years of investment in conservation success. In turn, options other than law enforcement inside PAs may be necessary to reduce tropical deforestation.

An estimated 735 million people live near remote tropical forests because agricultural land, an increasingly scarce resource remains abundant at the forest margin (Chomitz et al., 2007). In the absence of tangible benefits to conserve tropical forests, farmers seek to maximize profits by clearing protected forests for cash crops (Angelsen, 1999). In southern Sumatra, farmers grow coffee instead of working elsewhere (e.g. in the off-farm sector) because rural labour is poorly compensated (Rp. 20000 day^{-1} ~ US$ 2.2 day^{-1} in 2006) (Budidarsono et al., 2000). Therefore, higher local prices for coffee combined with low labour costs, rather than coffee price per se, may be the synergistic underlying cause of deforestation in Indonesia's main robusta coffee producing region. Due to the lack of reliable time-series data on rural wage rates the data could not test this hypothesis. Nevertheless, this suggests that the other key strategies to reduce coffee-related deforestation within PAs lies in raising rural wages relative to coffee prices outside PAs, as also suggested for flagship species in Africa (Milner-Gulland and Leader-Williams, 1992).

Agricultural intensification has been proposed as one appropriate way to simultaneously boost farmer income and reduce deforestation (Angelsen, 1999; Raynolds et al., 2007). In essence, it is argued that higher agricultural yields outside PAs may discourage farmers from working illegally inside PAs. By producing ~792 kg of coffee ha^{-1} yr^{-1}, Indonesia currently lags behind Colombia (~1220 kg ha^{-1} yr^{-1}), Brazil (~1000 kg ha^{-1} yr^{-1}) and Vietnam (~1540 kg ha^{-1} yr^{-1}) in terms of productivity (ICO, 2007). But, the Indonesian national government plans to make Indonesia a prime coffee producer by 2025 and will seek to increase production to 865,000 tons by improving productivity to ~1000 kg ha^{-1} yr^{-1} (http://www.indonesia.go.id). Nevertheless, such programs for agricultural intensification may enhance expected profits from coffee farming, which could attract migrants to coffee regions, and therefore deflate wages and boost rather than reduce deforestation in PAs (Angelsen, 1999; Dietsch et al., 2004).

Certification of origin for sustainable robusta coffee has also been proposed as another appropriate way to increase farmers' income and reduce deforestation inside PAs. WWF has recently urged major coffee buyers and roasters to adopt certification of origin around BBSNP (WWF, 2007). An important criterion for defining sustainability is that coffee should not be grown inside PAs. However, in practice enforcing this criterion is fraught with difficulty because coffee buyers and roasters are reluctant to manage the costs of robusta coffee certification (Sanderson, 2005). Low price premiums paid to coffee farmers for sustainable robusta coffee would not discourage farmers from following growing practices within protected areas. Equally, price premiums may encourage fraud within the coffee trade, given difficulties in differentiating between out-park and in-park grown coffee beans (WWF, 2007).

A third option to increase wages and reduce deforestation lies in national economic development. Better paid off-farm employment, sustained by more off-farm work opportunities in urban areas, with improved levels of rural education, may attract coffee farmers and their children away from PAs. In turn, this would increase rural wages and reduce incentives to cultivate coffee illegally inside PAs. This process, whereby forest cover first decreases then rebounds following economic development in surrounding areas has already occurred in several developed nations, while the same transition is also apparent in a number of developing economies (Rudel et al. 2005). For example, the island of Puerto Rico provides a dramatic example of the effect of increasing rural wages on reducing coffee-induced tropical deforestation and promoting forest re-growth (Rudel et al., 2000). Nevertheless, this path of economic development is a very complex and long-term task that requires extensive social investments at local, regional and national levels from a transparent and committed government.

Consequently, agricultural intensification, coffee certification, off-farm employment and higher education levels are unlikely to reverse deforestation trends across southwest Sumatra in the near future. Nevertheless, all have merit to address farmers' livelihood in an attempt to offer more equitable solutions to deforestation than mere law enforcement, as this study has raised an underlying issue; whether protecting forests by prohibiting their use by people represents a long-term solution in the context of surrounding poverty? Rethinking the role of protected areas and people in conservation has lead to the development of community forestry conservation projects, where a sustainable form of human use inside protected areas is tolerated (Djamhuri, 2008; Schwartzman et al., 2000). Community forestry inside PAs combined with law enforcement may under the right circumstances assist rural communities in the preparation of long-term plans for agricultural intensification, certification programs, off-farm employment and higher education levels.

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