Received: 1 April 2023 | Revised: 8 February 2024 | Accepted: 12 February 2024

DOI: 10.1111/conl.13010

Conservation Letters
A journal of the Society for Conservation Biology
Open Access
WILEY

LETTER

Improving well-being and reducing deforestation in Indonesia's protected areas

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Funding information
Leverhulme Trust; H2020 European Research Council, Grant/Award Number: 755956

Abstract

Protected areas (PAs) are central to sustainability targets, yet few evaluations explore outcomes for both conservation and development, or the trade-offs involved. We applied counterfactual analyses to assess the extent to which PAs maintained forest cover and influenced well-being across >31,000 villages in Sumatra and Kalimantan, Indonesia. We examined multidimensional aspects of well-being, tracking education, health, living standards, infrastructure, environment, and social cohesion in treatment and control villages between 2005 and 2018. Overall, PAs were effective at maintaining forest cover compared to matched controls and were not detrimental to well-being. However, impacts were highly heterogeneous, varying by island and strictness of protection. While health, living standards, and infrastructure aspects of well-being improved, education access, environmental conditions, and social cohesion declined. Our analysis reveals the contexts through which individual PAs succeed or fail in delivering multiple benefits and provides insights into where further on-ground support is needed to achieve conservation and development objectives.

KEYWORDS
counterfactual, evaluation, Kalimantan, poverty, Sumatra, tropical forest

1 | INTRODUCTION

Protected areas (PAs) are common tools to help reverse biodiversity decline and maintain ecosystem services. Yet, despite global commitments to expand PAs (UNEP-WCMC, IUCN, 2020), not all PAs are effective at achieving desired conservation goals (Ferraro et al., 2013). Crucially, PAs may also have unintended consequences in neighboring communities by restricting access to resources (Brockington & Wilkie, 2015; McKinnon et al., 2016), particularly in tropical countries where trade-offs occur between conserving globally significant biodiversity and development opportunities for local communities (Kabra, 2018).

Despite increases in the amount of area under protection, the extent and magnitude to which PAs achieve desired outcomes remain unequal within and between countries globally (UNEP-WCMC, IUCN, 2020). PAs have helped avoid deforestation (Gaveau et al., 2009), improve species protection (Taylor et al., 2011), and maintain ecosystem services (Resende et al., 2021), but the purported successes of PAs can be overstated, particularly as many global evaluations have not adequately considered counterfactual outcomes (Andam et al., 2013). Bias in PA placement to areas of low cost and experiencing few threats contributes little additional benefit than the counterfactual scenario of no protection (Joppa & Pfaff, 2009; Venter et al., 2018). Placement bias also leads to the unequal representation of species and ecosystems, resulting in uneven impacts in countries and local communities (Maxwell et al., 2020).

The use of conservation outcomes as the sole indicator of PA performance has drawn criticism due to the unintended impacts of PAs on people (Brechin et al., 2010). PAs can bring new income opportunities (e.g., tourism, Ferraro & Hanauer, 2014), but can also lead to detrimental outcomes for neighboring communities if they bear the cost of restricted access to conserved land (Brockington & Wilkie, 2015). A lack of adequate stakeholder consultation and failure to consider socioecological constraints can also result in diminished support for PAs and reduced effectiveness (Linkie et al., 2008; Oldekop et al., 2016). In worst-case scenarios, exclusion from land and decision-making processes can exacerbate conflict, inequality, and poverty (Brockington & Igoe, 2006). Understanding the conditions under which PAs deliver beneficial environmental outcomes without making local people worse off, and better still, contribute to well-being, is crucial to achieving conservation and sustainable development goals.

Causal inference methodologies assess interventions relative to a counterfactual scenario and have greatly improved our understanding of PA impacts and effectiveness (e.g., Ferraro & Hanauer, 2014). Yet, despite the increased uptake of these methods globally, conclusions are mixed. For example, increases in the strictness of protection appear to improve conservation outcomes of PAs on a global scale (Shah et al., 2021), but not necessarily at the national or regional level (Ferraro et al., 2013). Conversely, PAs reduce poverty when evaluated at national level (Andam et al., 2010), but localized impacts are nuanced (Clements et al., 2014). Evaluations of social impacts of PAs, and the trade-offs between social and environmental objectives, are often limited by the availability of socioeconomic information at sufficient scale and resolution to compare the impact of individual PAs robustly (Naidoo et al., 2019). As such, many evaluations are either limited to coarse-scale indicators that do not account for the multidimensional nature of well-being (Naidoo et al., 2019), or are undertaken at a fine scale using detailed socioeconomic metrics restricted to a small subset of PAs (Jones et al., 2017). Appropriate impact evaluation methodologies coupled with large-scale and detailed socioeconomic data are needed to improve our understanding of whether PAs meet their conservation objectives at no detriment to nearby communities, and help reveal conditions important for success.

Here, we use causal inference methods to evaluate the impact of PAs on forest conservation and multidimensional well-being outcomes in Indonesia where industrial expansion of agriculture and mining has accelerated development and reduced the number of people living in absolute poverty, particularly in rural areas (Suryahadi et al., 2012). Yet, at the same time, an extensive PA network has been implemented to curb high deforestation rates (Iskandar, 2022). Trade-offs between such conservation and development objectives are particularly acute in the west of the country in Sumatra and Kalimantan (Borneo) (Dwiyahreni et al., 2021; Santika et al., 2021) where around 10% of land is protected for conservation (121 PAs across 46,100 km^2 and 34 PAs across 54,000 km^2, respectively; Figure 1).

We determine the extent to which PAs reduced deforestation and affected well-being in Sumatra and Kalimantan, employing a multidimensional well-being index for 31,990 villages over 13 years between 2005 and 2018. We apply a control–impact framework with statistical matching to address three research questions: Do PAs reduce deforestation, and does the strictness of protection influence this? What are the implications of PAs on well-being of neighboring communities? How do changes in deforestation and well-being near individual PAs differ within and between regions of Indonesia?

2 | METHODS

2.1 | PA treatments

PA data (IUCN categories Ia–VI) were validated against the Indonesian legal land-use database (Indonesian Ministry of Forestry, 2010), and villages with boundaries that overlapped PAs were identified as treatment villages. As both the average village size and the area of overlap varied between villages and island (Figure S2.1; Table S2.2), villages found to overlap PAs by more than the median value for each island (≥25% in Sumatra, 759 villages; ≥34% in Kalimantan, 169 villages) were classified as treated,

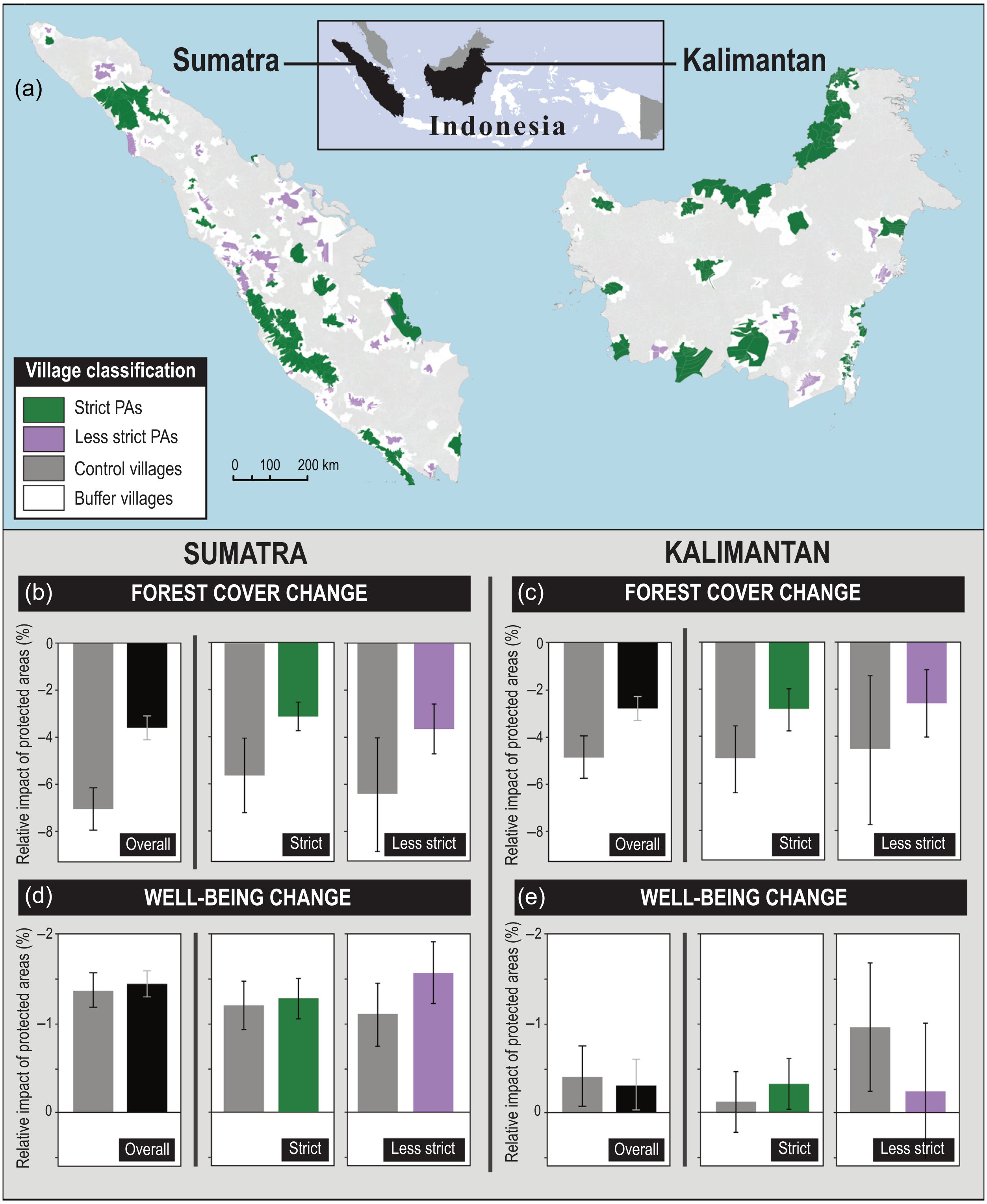

FIGURE 1 (A) Distribution of villages overlapping strict (green) and less-strict (purple) protected areas (PAs) in Sumatra and Kalimantan, Indonesia. Villages in gray were included in the pre-match control pool; buffer villages in white were excluded from analysis. (B, C) Average changes in forest cover over the 13-year study period (2005–2018) between PAs and matched controls in Sumatra and Kalimantan, respectively. Black bars depict cumulative PA results compared to matched controls shown in gray, green bars depict strict PAs, and purple bars show less-strict PAs. (C, D) Average changes in well-being in villages neighboring PAs versus controls in Sumatra and Kalimantan. For each evaluation, the matching was undertaken separately for PAs with strict (green) and less-strict (purple) protection, as well as combined (black). Error bars depict 95% confidence intervals.

whereas those that fell below the threshold were excluded. This resulted in the inclusion of 78 PAs (60 Sumatra and 18 Kalimantan; Table S1.1). Due to insufficient overlap with any villages and small spatial size (average ~10 km^2), 64 PAs were excluded from analysis, as signals from PAs would be difficult to discern at village level.

As PAs are likely to have socioecological impacts that extend beyond park boundaries, we applied a 10-km buffer around each PA to isolate the impact of protection from potential spillover effects. Buffers of this size are typical of other impact evaluations (Naidoo et al., 2019; Oldekop et al., 2016) and serve to minimize the effect of spatial autocorrelation between matched pairs of treated and control units (Negret et al., 2020). Villages outside the buffer region were classified as controls (15,370 in Sumatra and 4374 in Kalimantan). Treated villages were then further stratified for separate analysis. Those overlapping with national parks and wildlife reserves (IUCN categories Ia–II) were classified as "strict" PAs, whereas those overlapping hunting parks, game reserves, grand forest parks, and nature recreation parks (equivalent to IUCN categories III–VI) were classified as "less strict." Those that overlapped both types of PA ($n = 8$) were classified according to the type with the largest area of overlap. This resulted in three treatments (All, Strict, and Less-strict PAs), which were matched and analyzed separately for each island. We assumed stable unit treatment values, although we note that there is likely to be variation between regulatory criteria documented by IUCN and realized actions on the ground (Dwiyahreni et al., 2021; Larsen et al., 2019).

2.2 | Forest data

As a primary goal of PAs is to protect forest, we determine PA effectiveness based on deforestation incurred. Forest cover estimates from 2005 and 2018 were derived using the Global Forest Change (GFC) dataset (v1.8; Hansen et al., 2013), and defined forested pixels as >70% tree canopy cover in 30-m-resolution Landsat data following established protocols for tropical moist forest (Santika et al., 2020; Voigt et al., 2022). Forest loss is the removal or mortality of this tree cover. Following established protocols, we distinguished forest from plantations using the extent of forest labeled as primary in 2000 by Margono et al. (2014). The change in total forest cover between 2005 and 2018 was calculated for each village.

2.3 | Multidimensional well-being

Previous investigations of PA impacts on people have measured benefits based on the absence of poverty (Hanauer & Canavire-Bacarreza, 2015), or measures of well-being that are closely linked with material wealth (Clements et al., 2014). Here, we consider well-being as a multidimensional combination of social, economic, and environmental conditions that contribute to an individual's quality of life and their capacity to withstand and overcome challenges (Ruggeri et al. 2020). To measure multidimensional well-being, we compiled data from Indonesia's village-level census, *Potensi Desa* (PODES), which is administered every 3–4 years and spatially linked to village boundaries ($n = 24{,}000$ in Sumatra; $n = 5600$ in Kalimantan in 2018). We used data from five consecutive census events (2005, 2008, 2011, 2014, and 2018) to form a Multidimensional Well-being Index (MWI), comprising 18 equally weighted indicators across six dimensions: living standards, health, education, environment, social cohesion, and infrastructure and services (Tables 1 and S3). Differences in village boundaries and census questions prior to 2005 made it difficult to utilize data before this period. The index and dimensions were calculated based on how many basic needs were absent in a village (i.e., by assigning a value of 0 if a village met the well-being threshold, or 1 otherwise, denoting deprivation). We then calculated an overall well-being score per village as the cumulative value of the 18 indicators and calculated the change in this score over the study time period for each village.

2.4 | Confounding variables

We controlled for the potential influence of biophysical and sociopolitical covariates on forest and well-being outcomes by assigning average covariate values to each village unit. Biophysical attributes comprised slope, elevation, baseline forest cover (in 2005), soil type, and precipitation (see Material S1.2 and S1.3), while social–political values comprised baseline well-being (in 2005), accessibility, main income source, population size, and village area (Table S4).

2.5 | Statistical matching

We used pair matching to identify treatment and control villages with similar covariate values, and applied a control–intervention analysis to compare changes in forest cover and well-being (overall and dimension-specific) between PA villages and matched controls throughout the study period. The process was repeated separately for the three treatments (i.e., all, strict, and less-strict PAs, each in Sumatra and Kalimantan; six analyses in total). We assessed the efficacy of five matching approaches and confirmed matching with calipers and with replacement to be

TABLE 1 Indicators and dimensions of our Multidimensional Well-being Index (MWI) derived from Indonesia's PODES census.

Dimension	Indicator	Threshold for deprivation	Supporting reference
Education	Access to primary schools	There are no facilities within the village.	VDI, SDGs
	Access to high schools	Facilities are greater than 3 km away.	VDI, SDGs
	Presence of supplementary literacy programs	No literacy programs are available.	VDI, SDGs, Iskandar, 2022
Health	Malnutrition	There are more than two sufferers of malnutrition per 1000 population.	VDIs, SDGs
	Fatalities from preventable diseases	Mortality has occurred due to preventable illnesses including malaria and vomiting/diarrhea.	SDGs, Minister of Health Decree
	Access to health facilities	No healthcare facilities within the village, and the nearest polyclinic is >19 km away.	VDIs, SDGs
Living standards	Source of drinking water	Water is primarily obtained via an un-improved source (e.g., pond, river, stream, rain).	VDIs, SDGs
	Sanitation facilities	The majority of households do not have access to a private toilet facility.	VDIs, SDGs, Santika et al., 2021
	Source of cooking fuel	The primary source of cooking fuel used by households is not gas or LPG.	VDIs, SDGs, Santika et al. 2021
Infrastructure and services	Social security	More than 10% of households hold an official poverty letter (Surat Keterangan Tidak Mampu)	Fiarni et al., 2013
	Credit facilities	There is no access to any form of credit.	Santika et al. 2021
	Market access	There is no permanent or semipermanent market, and the nearest permanent or semipermanent market is >10 km away.	VGI
Environment	Air pollution	Air pollution was reported within the past year.	SDGs, Santika et al. 2021
	Water pollution	Water pollution was reported within the past year.	SDGs, Santika et al. 2021
	Natural disasters	A landslide, flood, or earthquake has occurred within the village in the past 3 years.	Hallegatte et al. 2017
Social cohesion	Crime	More than three types of crime have been reported to have occurred in the past year.	Sugiharti et al., 2022
	Conflict	Mass conflict has occurred within the past year.	Santika et al. 2021
	Community participation	There have been no mutual cooperation activities.	Acket et al., 2011; Iskandar, 2022; Santika et al., 2021.

Note: The framework aligns with the Sustainable Development Goals (SDGs) and uses thresholds drawn from Indonesia's Village Development Index (Indek Pembangunan Desa, VDI) (Section 2 in the Supporting Information).

the optimal approach for Sumatra, while genetic matching was optimal for Kalimantan (Material S5). A standardized mean difference of <0.1 was used as a threshold to determine balance between treatment and control groups for each covariate (Schleicher et al., 2020).

2.6 | Analysis

A control–intervention analysis was employed to estimate the average treatment effect of protection on forest cover and overall well-being outcomes between control and treatment groups over time (2005–2018) (Table S6.1). We used an OLS regression to test the statistical significance of the treatment effects (Table S7) whereby the dependent variable of interest included the change in total forest cover or well-being between 2005 and 2018. This process was then repeated to assess changes in the six well-being dimensions. All analyses were undertaken in the R version 3.6.3 "MatchIt" package (Ho et al., 2011). To understand the contribution of individual PAs to overall deforestation and well-being outcomes, a supplementary analysis was conducted to compare average changes in outcome variables.

3 | RESULTS

Villages neighboring PAs experienced significantly less deforestation compared to matched controls. Those in Sumatra experienced 3.4% less deforestation than control villages ($p = 0.026$) overall, whereas in Kalimantan deforestation in PA villages was 2.1% lower than in matched controls ($p = 0.005$) (Figure 1). Over the 13-year period, well-being improvements were similar between PA villages and matched controls in Sumatra and Kalimantan. However, changes in overall well-being outcomes masked important variation corresponding to both the strictness of protection and individual well-being dimensions.

Strict and nonstrict PAs on each island experienced ~2% less deforestation between 2005 and 2018 than matched controls (2.4% and 2.1% less deforestation in villages neighboring strict PAs for Sumatra and Kalimantan, respectively; reductions of 2.9% and 1.9% in less-strict PAs) (Figure 1A,B; Tables S6.1 and S7). In contrast, no detectable difference between overall well-being in PA villages and controls was found on either island; however, the strictness of protection was associated with different outcomes (Figure 1D,E). In Sumatra, villages near PAs tended to experience greater well-being improvements than controls, whereas in Kalimantan, results were more variable. While well-being improved in villages near less-strict PAs, the magnitude of improvement was lower but not significantly different than that experienced in control villages.

Patterns in overall well-being masked significant variation among well-being dimensions (Figure 2; Tables S6.2 and S7). On both islands, villages near PAs experienced improvements to health, living standards, and infrastructure dimensions. However, declines in education, social, and environmental well-being were experienced at the same time. Sumatran villages experienced the greatest improvements to health-based indicators regardless of location, while improvements to living standards were slower to accrue near strict PAs than in controls. Conversely, in Kalimantan, improvements in health indicators were marginal across treatments, while living standards improved in strict and nonstrict PAs, with the former being significantly higher than control villages ($p = 0.03$). All villages experienced a decline in education, social, and environmental well-being, with the deterioration of the latter dimension exacerbated near less-strict PAs in Kalimantan, where villages experienced statistically significant worsening of environment conditions compared to controls ($p = 0.017$) (Table S7).

Supplementary analysis of all PA villages (i.e., those included in the unmatched treatment pool) revealed substantial variation in conservation and well-being outcomes associated with individual PAs within and between islands. Of the 60 Sumatran PAs examined, 25 (41%) were associated with <5% deforestation over the study period (an equivalent of <0.5% p.a. and less than background deforestation rates of 0.76% p.a. and 1.5% p.a. for Borneo and Sumatra, respectively) and above-average well-being improvements compared to that experienced across all villages during the study period (Figure 3). However, 13 PAs (22%) experienced a trade-off between reducing deforestation in the park and improving well-being. They lost <5% forest between 2005 and 2018 (i.e., <0.5% annually), while improvements to well-being were below the background average. Conversely, 16 (27%) PAs were associated with >5% deforestation and well-being improvements. Six PAs (10%) experienced both high deforestation and reduced well-being, implying that neither conservation nor development objectives were met.

Of the 18 PAs in Kalimantan, 28% experienced <5% deforestation and above-average improvements to well-being and 34% of PAs experienced low levels of deforestation along with below-average changes to well-being (Figure 3). High levels (>5%) of deforestation were associated with improvements to village well-being in 16% of cases, while 22% of PAs experienced both deforestation and deteriorating well-being conditions.

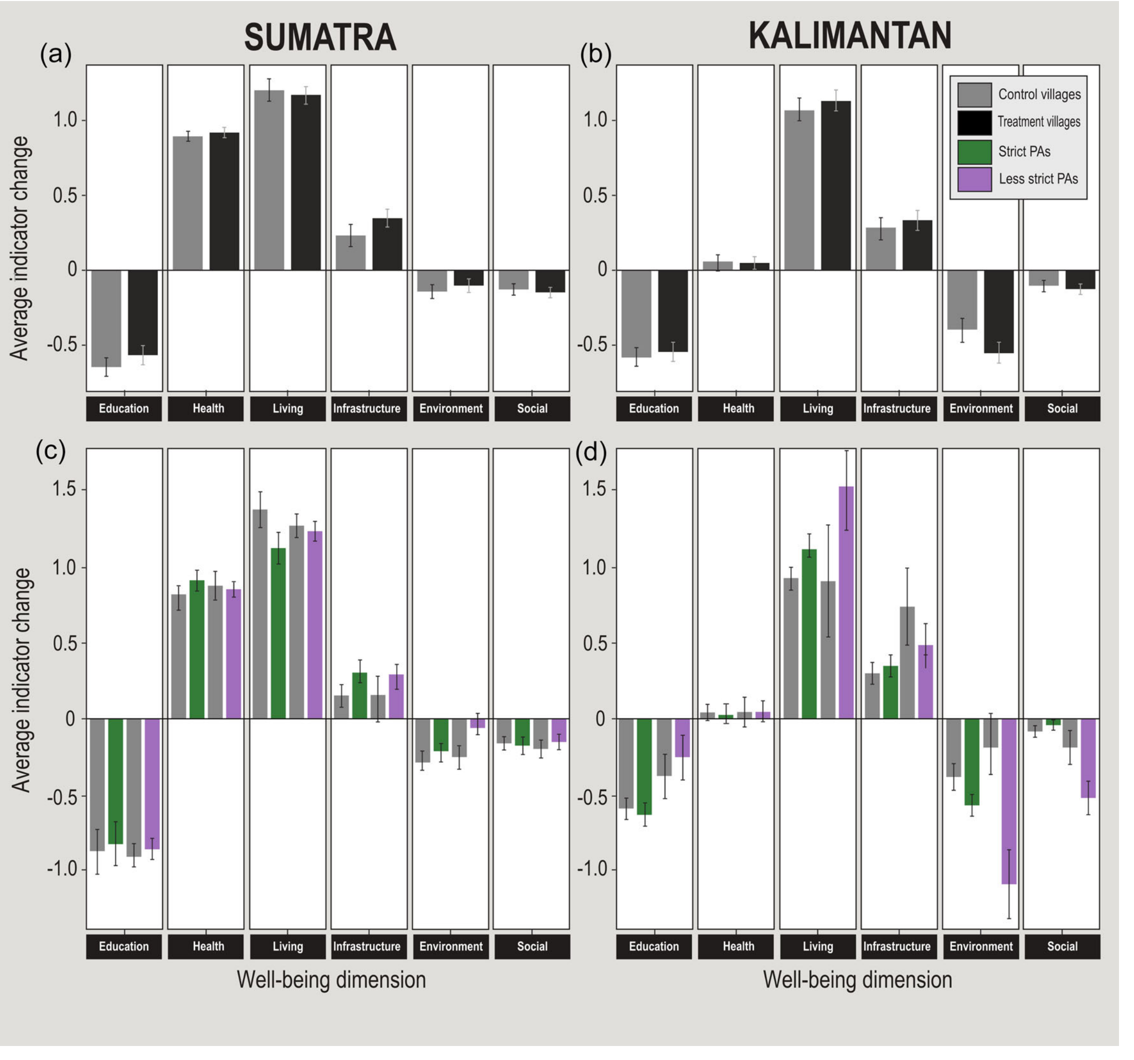

FIGURE 2 Average change in dimension-level well-being scores between villages overlapping PAs (black) and control villages (gray) in Sumatra and Kalimantan between 2005 and 2018 (top). Average difference in well-being dimensions between strict (green) and less-strict (purple) PA villages compared with respective matched controls (bottom). Error bars depict 95% confidence intervals. [Correction added on 03/24/2024, after first online publication: Figure 2 was replaced with the correct version.]

4 | DISCUSSION

Overall, PAs were associated with reduced rates of deforestation in Sumatra and Kalimantan without compromising well-being in nearby villages. Yet, changes in deforestation and well-being varied by island and levels of protection. In Kalimantan, deforestation was similar in all PAs regardless of their level of protection, and the greatest well-being improvements occurred in villages near strict PAs. In Sumatra, PAs were associated with significant reductions in deforestation as well as improvements in well-being, although the latter change was not statistically significant compared to controls. Less-strict PAs were associated with marginally higher deforestation than strict PAs, but greater well-being improvements. This implies that the overall performance of PAs depends on the local context, not just the strength of protection.

Well-being improved across Indonesia during the study period, with similar increases occurring in PA and control villages. Improvements in living standards experienced in both PA and control villages reflect Indonesia's economic growth and development policies focused on the Millennium and Sustainable Development Goals (Iskander, 2022). For instance, liquified petroleum gas access was provided to 50 million households between 2005 and 2012 (Thoday et al., 2018), and efforts to improve sanitation and access to safe drinking water were similarly effective (Odagiri et al., 2020). The intensity of program rollouts varied geographically (Odagiri et al., 2020), however, which may explain why living standards varied among treatment

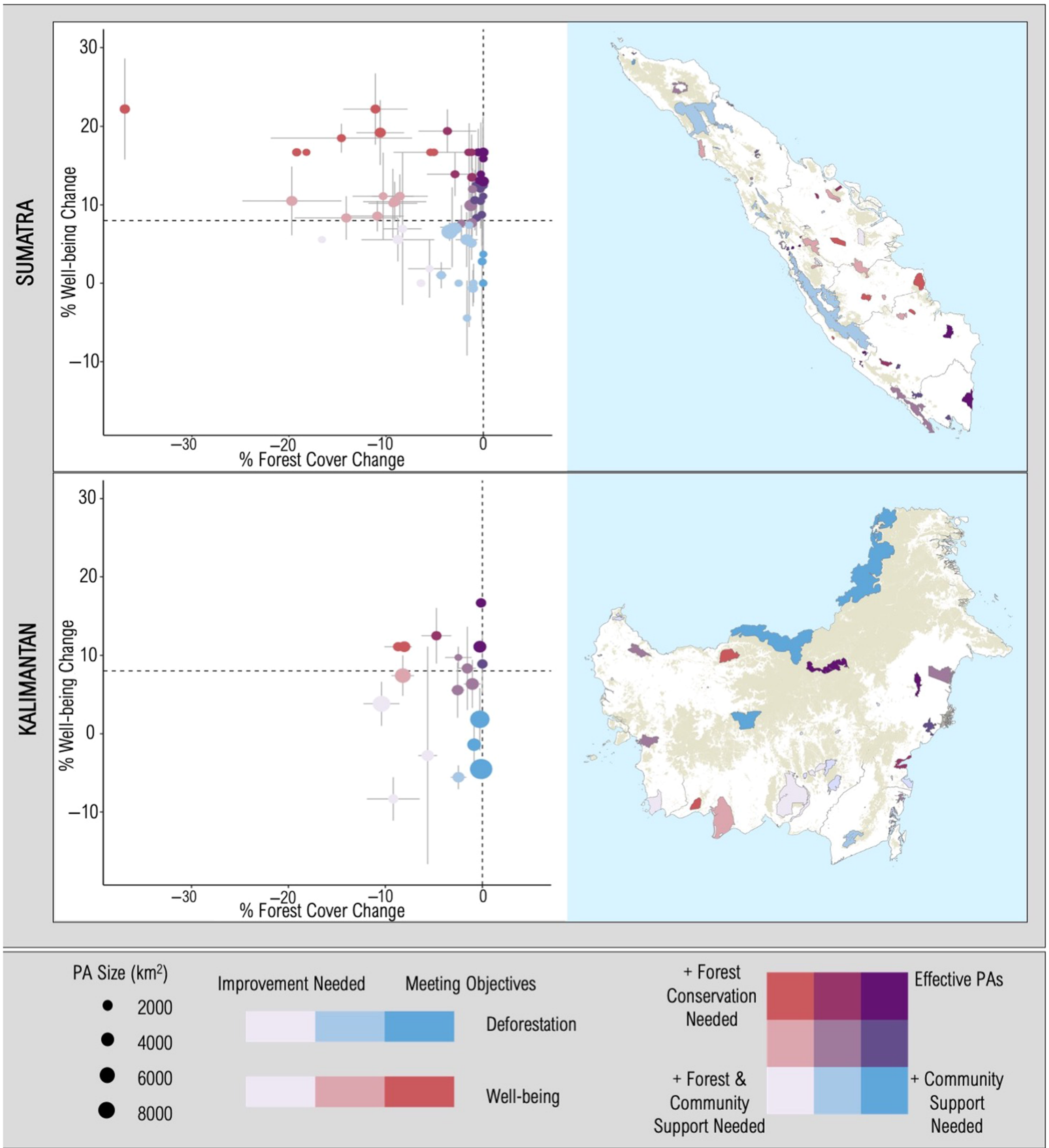

FIGURE 3 Performance of individual protected areas (PAs) in achieving forest conservation and well-being outcomes in nearby villages. Scatterplots depict average (±95% confidence intervals) forest cover and well-being change in all intersecting villages for each PA in Sumatra and Kalimantan. Point size reflects PA area (km^2). The vertical dashed line depicts zero deforestation since this is an assumed PA goal that aligns with global ambitions to end deforestation by 2030. The dashed horizontal line depicts the average change in overall well-being across all villages in Sumatra and Kalimantan, and thus represents the aggregated average change in well-being across all villages for each island. PAs located further to the left of the vertical line have experienced greater reductions in forest cover, while being above the horizontal line indicates higher than average improvements in village well-being. PA colors reflect levels of success in meeting objectives with increasing red saturation depicting improved well-being outcomes and increasing blue saturation depicting positive forest conservation outcomes. PAs in purple are therefore associated with more effective forest protection and improved well-being.

groups and islands. Improvements to health as well as infrastructure and services around PAs may reflect localized efforts to incentivise pro-conservation behaviours through the provision of credit facilities or alternative enterprises such as ecotourism and community forestry around some parks (Jones et al., 2020; Knott et al., 2021).

Education access worsened across villages on both islands. Educational attainment gaps persist between rural and urban regions in Indonesia (Iskander, 2022) with distance, poor transport, and damage to critical infrastructure restricting participation (Pramana et al., 2021). Similarly, overall declines in social cohesion, particularly around less-strict PAs in Kalimantan, suggest that conservation measures may exacerbate social conflict. Participatory forest management may therefore lead to improved outcomes if sustainable use is promoted in lieu of strict forms of protection (Friedman et al., 2022; Oldekop et al., 2016), as is the case for Indonesia's social forestry scheme (Santika et al., 2019).

Across both islands, most individual PAs met the primary objective of protecting forest without detriment to neighboring communities within the study period. However, these attainments followed years of deforestation prior to the study period (Gaveau et al., 2009). Our analysis (Figure 3) reveals that some PAs require additional support to meet forest protection goals without disadvantaging surrounding communities. Trade-offs between PA conservation and development outcomes (49% of cases in Sumatra; 50% in Kalimantan) suggest linking conservation goals with the needs of local people should remain a high priority for PA planning and management (Supriatna & Margules, 2022). While the primary objectives for PA designation and management may vary between individual PAs, learning from PA successes and applying these lessons to less effective ones will assist in avoiding unintended outcomes. Any future expansion of the PA estate would benefit from clear usage policies and participatory planning.

Well-being outcomes vary between islands and indicators, emphasizing the importance of considering the multidimensional nature of well-being when evaluating the impacts of PAs and other conservation policies on neighboring communities. While we reveal important nuances in well-being outcomes, indicators were measured at the village level and so could conceal potential heterogeneity between households (Naidoo et al., 2019). Similarly, while the selected well-being indicators represent facets of Indonesia's sustainable development goals, they are not exhaustive and the impacts of PA development on equity and resilience within communities require further investigation. As the focal period for our analysis does not include trends prior to the designation of the PAs, explicit causality between PAs and deforestation and well-being outcomes should not be inferred. In addition, it is possible that the influence of PAs on deforestation and well-being will vary depending on the extent to which a village area is impacted by PA regulations. Further evaluations that account for trends prior to implementation as well as the proportion of the village area under PA designation will improve this evidence base.

Drawing inference from broadscale counterfactual analyses, our appraisal highlights that PA outcomes are dependent on local context. Our finding of heterogenous impacts of PAs on communities is highly relevant to global ambitions for expanding the PA network, such as the CBD 30-by-30 target. We emphasize the need for more nuance in impact evaluation approaches to provide a robust evidence base for informing PA expansion efforts. Trade-offs in PA outcomes also need to be further scrutinized to understand contributions toward contrasting sustainable development goals since there is variation in the ability of PAs to meet sustainability objectives, including poverty alleviation and ecosystem protection. Consequently, a carefully considered national and international PA network is needed to ensure targets for representation are met, while securing equitable benefits for people more broadly.

ACKNOWLEDGMENTS

The research was funded by a Leverhulme Research Leadership Award to M.J.S., with permission granted from Indonesia's National Research and Innovation Agency (formally RISTEK; permit 2/TU.B5.4/SIP/VIII/2021). This research is part of a project that has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 grant agreement number 755956 awarded to F.A.V.S.J.

DATA AVAILABILITY STATEMENT

Datasets used to conduct our analysis are publicly available from the cited references (forest cover data available from https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.7.html; socioeconomic data from https://mikrodata.bps.go.id/mikrodata/index.php/catalog/PODES).

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How to cite this article: Morgans, C. L., Jago, S., Andayani, N., Linkie, M., Lo, M. G. Y., Mumbunan, S., St. John, F. A. V., Supriatna, J., Voigt, M., Winarni, N. L., Santika, T., & Struebig, M. J. (2024). Improving well-being and reducing deforestation in Indonesia's protected areas. *Conservation Letters*, e13010. https://doi.org/10.1111/conl.13010