nature communications

Article https://doi.org/10.1038/s41467-026-69081-0

Distributional effects of marine conservation on coastal livelihoods in Eastern Indonesia

Received: 9 January 2024

Accepted: 23 January 2026

Published online: 26 May 2026

Check for updates

Duong Trung Le [1,2,3], Gabby N. Ahmadia [4], Indah Anggriyani Ratih [5], Kelly Claborn [4,6], Estradivari [7], Muhammad Erdi Lazuardi [8], Dariani Matualage [5], Phillip. M. Mohebalian [4], Hellen Nanlohy [9], Ni Kadek Sri Pusparini [10], Ranaivo Rasolofoson [2,11], Kezia E. Salosso [5], Natelda R. Timisela [9], Fitryanti Pakiding [5,12], Louise Glew [4,12], Michael B. Mascia [2,12] & David Gill [2,12]

Marine protected areas (MPAs) are widely adopted to conserve marine biodiversity, yet their distributional impacts on resource-dependent communities remain underexplored. This study investigates socioeconomic inequality linked to MPAs in eastern Indonesia using a quasi-experimental design and multi-round household surveys of over 10,000 households across 180 coastal settlements in 10 MPAs (2010–2017). We assess poverty through objective (asset-based index) and subjective (perceived economic trends) measures. Findings reveal overall poverty reduction and persistent pre-existing inequalities by gender, age, occupation, and tenure rights. MPAs did not cause short-term economic losses or widen objective inequality but constrained perceived economic improvement, particularly among female-headed households. Community engagement moderated these effects: gender disparities were greater where female participation in groups was low. These findings suggest that promoting inclusive participation can help ensure more equitable conservation outcomes.

Among the major environmental conservation initiatives, protected areas (PAs) are increasingly being implemented by governments and other institutions to meet the dual goals of alleviating ecosystem degradation and sustaining human well-being[1–3]. The prevalence of PAs and ambitious calls to rapidly increase PA coverage to 30–50 percent of the land and ocean[3], highlights the urgent need to understand and measure PA impacts across both ecological and social outcomes. Relative to the more prominent social science research measuring impacts of terrestrial PAs[4–6], the current understanding of how marine conservation interventions affect human well-being is limited[7–9], despite rapid growth in both the size and number of these initiatives in the last few decades[10].

The lack of scientifically rigorous evidence on the diversity of social impacts of PAs on coastal communities is a pressing knowledge gap that could hinder progress towards more effective and equitable conservation and sustainable development[11,12]. Within the literature on marine protected areas (MPAs), there have been calls for greater evidence on how the magnitude of marine conservation impacts varies among social groups, in order to better inform equitable policy development[11,13]. The existing literature on this topic is predominantly descriptive, with limited quantitative studies often constrained by isolated and small study samples, unidimensional outcome measures, and the lack rigorous impact-evaluation study designs[7,8,14]. While studies have acknowledged social benefits of marine conservation on

[1]The World Bank, Washington, DC, USA. [2]Duke University, Beaufort, NC, USA. [3]Fulbright University Vietnam, Ho Chi Minh City, Vietnam. [4]World Wildlife Fund-U.S., Washington, DC, USA. [5]Universitas Papua, Manokwari, Papua Barat, Indonesia. [6]Arizona State University, School of Human Evolution and Social Change, Tempe, AZ, USA. [7]Leibniz Center for Tropical Marine Research, Bremen, Germany. [8]World Wildlife Fund-Indonesia, Bali, Indonesia. [9]Universitas Pattimura, Ambon, Indonesia. [10]Wildlife Conservation Society, Bogor, Jawa Barat, Indonesia. [11]School of the Environment, University of Toronto, Toronto, ON, Canada. [12]These authors jointly supervised this work: Fitryanti Pakiding, Louise Glew, Michael B. Mascia, David Gill. e-mail: dle6@worldbank.org

 https://doi.org/10.1038/s41467-026-69081-0

average[7], a growing concern is that such benefits are often unevenly distributed across the population, resulting in or exacerbating pre-existing inequalities[15–17], conflict, or other social harm[18,19]. Such unequal outcomes can also lead to resentment amongst affected groups and increase non-compliance with MPA regulations[20]. Thus, a lack of understanding of the differential impacts of conservation can jeopardize both social and ecological goals[21,22]. Critically assessing the distribution of impacts across social groups can help policymakers identify and account for the most marginalized and vulnerable groups, thereby tailoring adequate support to mitigate social inequity[23,24].

This study examines the socioeconomic inequality linked to MPA establishment in eastern Indonesia. This work contributes to the nascent understanding of the differential social impacts of MPAs by employing a quasi-experimental study design to assess the impacts of a network of MPAs on inequality in coastal communities in Eastern Indonesia. We provide a quantitative assessment of the distributional effects of MPAs on socioeconomic outcomes across social groups through the lens of poverty—a crucial aspect particularly relevant to coastal poor communities in developing countries[25–27]. We use a primary household survey dataset of over 10,000 households to develop metrics of both objective and subjective dimensions of economic well-being. Our work advances the current literature studying the social impacts of PAs in several ways. First, while the understanding of aggregate impacts is important for policymakers in designing net-beneficial conservation interventions, our analysis assesses the heterogeneity in impacts among different social subgroups, thereby providing critical insights on equality of conservation impacts. Second, our study employs an unprecedented and potentially one of the largest monitoring datasets capturing social and ecological conditions before and after the implementation of 10 MPAs in Eastern Indonesia, encompassing over 10,000 household surveys within 180 characteristically similar treated (MPA) and control (non-MPA) coastal settlements between 2010 and 2017. Third, relying on this quasi-experimental survey design, we employ a robust impact-evaluation method to provide causally inferred evidence on how MPAs differentially affect the economic well-being of different societal groups. The empirical approach enables us to disentangle changes in household economic well-being induced by MPA intervention from the broader economic trends observed in the seascapes and other potential rival explanations. Fourth, our study takes place in a region containing the world's greatest diversity of corals and reef fishes, as well as a strong sustainable development priority due to high poverty rates and resource dependency of the local community[28]. It is therefore an ideal location to assess how conservation can contribute to equitable development. The study-site setting also allows us to evaluate the economic-well-being impacts of marine conservation initiatives designed to incorporate the existing customary rights and norms of the local community. Indeed, it has been shown that PAs designed with a recognition of the rights, norms, and practices of locals and including locals in decision-making can mitigate some negative impacts[29–32]. Therefore, understanding the heterogeneity of impacts from MPAs designed around existing customary rights can provide guidance toward their contribution towards meeting joint biodiversity and sustainable development goals within contexts of high poverty and resource dependency[33–36]. Knowing how groups are differentially affected can inform when conservation interventions result in synergistic social and environmental benefits[18,37,38] or instead produce tradeoffs and increase inequality[8,39,40]. We discuss the broader contribution of the paper related to the conservation literature in the Supplementary Discussion.

Results and discussion

MPA context

We assessed MPA impacts using a multi-round household monitoring survey in the Bird's Head Seascape (BHS) and Sunda Banda Seascape (SBS)—a seascape being bio-geographically defined as a network of MPAs—in the province of West Papua in Eastern Indonesia (Fig. 1). The decade-long monitoring program follows state-of-the-art methods for impact evaluation, employing a quasi-experimental study design to assess MPA effects on coral reef ecosystems and human well-being across multiple MPA networks. Between 2010 and 2017, trained enumerators surveyed 10,123 randomly-selected households located in 180 stratified-sampled settlements across 10 MPAs that together encompass 37,779 km^2 of the ocean. There are 124 settlements located inside the MPA boundaries, which constitute the treatment group in our quasi-experimental setting. The control units are settlements selected prior to monitoring that are located outside the MPAs with similar observable characteristics that may influence the probability of MPA establishment and its impacts, based on relevant bodies of theory, including social-ecological systems and common pool resource governance[28,41] (refer to the section "Results and discussion" for details). Importantly, baseline monitoring began after the MPA boundaries had been delineated, but prior to the enforcement of MPA regulations governing resource use. In each settlement, surveys were conducted at baseline and post-implementation at 2- or 3-year intervals (see "Study context" and "Survey design" in "Methods" for further details).

Figure 1 shows the location of the studied MPAs and all social monitoring settlements (Supplementary Table 1 documents the sampling details related to each MPA). There are noticeable heterogeneities in population and ocean coverage across MPAs. On average, MPAs in BHS—Mayalibit, Cenderawasih, Kaimana, Kofiau, Dampier, and Misool—are more remote, less populated, and larger in size, relative to the SBS' MPAs—Selat Pantar, Flores Timur, Kei Kecil, and Koon. We discuss our empirical approach that accounts for the geographical idiosyncrasies in the next section.

Empirical methodology

We considered the evaluation of MPA impacts on social outcomes from the sampling design stage before data collection. Sample control settlements are outside MPA boundaries and selected to have a high probability of containing the socio-demographic composition of households similar to MPA (treated) settlements. We specifically performed a "coarse matching" procedure where we selected sample control settlements that are similar to MPA settlements in terms of distance to market, predominant household occupation, ethnic composition, and political jurisdiction (see "Study context" and "Survey design" in "Methods" for more details). We therefore assume that the selected control settlements in our social monitoring program represent what would have happened had MPA settlements not protected (i.e., the counterfactual). Next, we fit this dataset under a difference-in-difference (DiD) model (Eq. 2)—an econometric estimation method popularly used for causal inference. Essentially, the identification strategy compares the average differences in household economic outcomes over time (i.e., between the pre- and post-intervention periods) across treated and counterfactual settlements. Our fully specified model controls for observable time-varying household factors potentially correlated with the treatment status and changes in economic well-being, as well as settlement-level fixed effects and calendar-year fixed effects—the former accounts for potential time-invariant confounders at the settlement level and the latter accounts for region-wide factors common to all settlements in a particular year (see "Econometric model" in "Methods" for a detailed discussion of the DiD model). Combined with the coarse matching procedure, the regression method seeks to ensure that the average treatment effects are estimated from the difference in economic outcomes between treated and control households that are most comparable to each other at baseline. The identifying assumption of our econometric approach is that, in the absence of the MPA intervention, the economic performance of the treated and control households would have been identical.

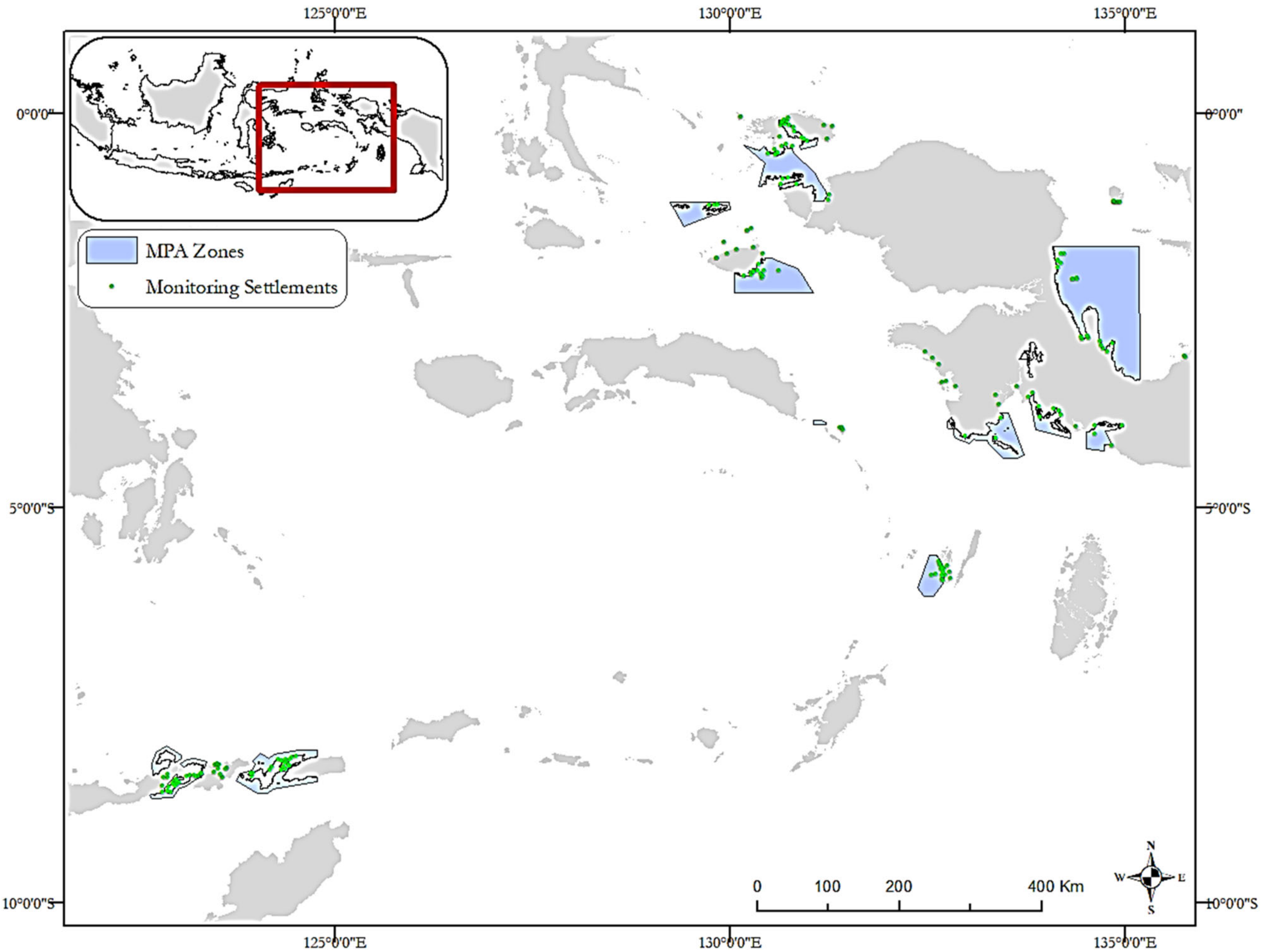

Fig. 1 | MPA study sites. Authors' illustration with a base WGS-84 map from GADM. Geographic distribution of the six and four marine protected areas and study sites (settlements) in the Bird's Head Seascape (BHS; upper right) and the Sunda Banda Seascape (SBS; lower left), respectively. Each green dot represents a surveyed settlement where household social data were collected during both baseline and follow-up survey rounds. Settlements located inside MPA zones constitute the treatment group. Settlements located outside the MPA zones and shown on the map are counterfactual units selected from the coarse-matching survey design.

We examined heterogeneity in households' economic well-being impacts among social groups across both objective and subjective dimensions. To measure objective impacts, we derive a household-level "poverty alleviation" index, constructed from a principal component analysis (PCA) of a suite of owned household staples and productive assets relevant to the local context. This method is common to most conventional studies that measure asset-based economic well-being[42–44]. Our subjective well-being outcome reflects a household's perception of the changes in economic condition that they experienced over the year prior to survey (see the "Methods" section for detailed discussions on the formation of economic-well-being indicators).

Baseline well-being, inequality status, and trends

The baseline descriptive statistics of the main variables in this analysis are presented in Supplementary Table 2. For the outcome variables of interest, the average values of the household asset index (material well-being) and perception of economic well-being (perceived well-being) are largely similar between the treatment and control groups at baseline. Across the seascapes, approximately a quarter of households perceived a stable or improved economic condition over the previous year (Supplementary Table 2). Further description of the covariates and subgroup compositions (e.g., other baseline household socio-demographics) is presented in the Supplementary Materials.

We assess the baseline differences in economic well-being across socio-demographic groups using the constructed asset index and subgroup categories, where a larger index represents more poverty alleviation. This analysis examines four social subgroups relevant to the existing conservation literature, including (i) gender (male- vs. female-headed households), (ii) fishery livelihood (households employed in fishery vs. non-fishery occupations), (iii) age cohort (working-aged vs. retired household head), and (iv) tenureship (*Adat* vs. *non-Adat* households—the Adat households being identified as individuals holding premium tenure rights to marine resources) (see "Methods" for details on the formation of subgroup identifiers).

As Fig. 2 highlights, the inequality in poverty prevalence exists and varies across social groups. Households headed by females, retired individuals, and those not holding premium tenure rights (non-Adat households) are, on average, exposed to greater poverty than their respective counterparts, as reflected by significant mean-difference *t*-tests. Supplementary descriptive evidence further indicates that these same disadvantaged groups are also less likely to report improvements in their economic well-being compared to their counterparts, underscoring the persistence of structural inequalities (see Supplementary Fig. 6).

Next, we use a settlement-level DiD regression model (Eq. 2) to assess the overall trend in economic well-being. We observe positive and significant broad trends in poverty reduction across the studied seascapes, both objectively and subjectively (Supplementary

https://doi.org/10.1038/s41467-026-69081-0

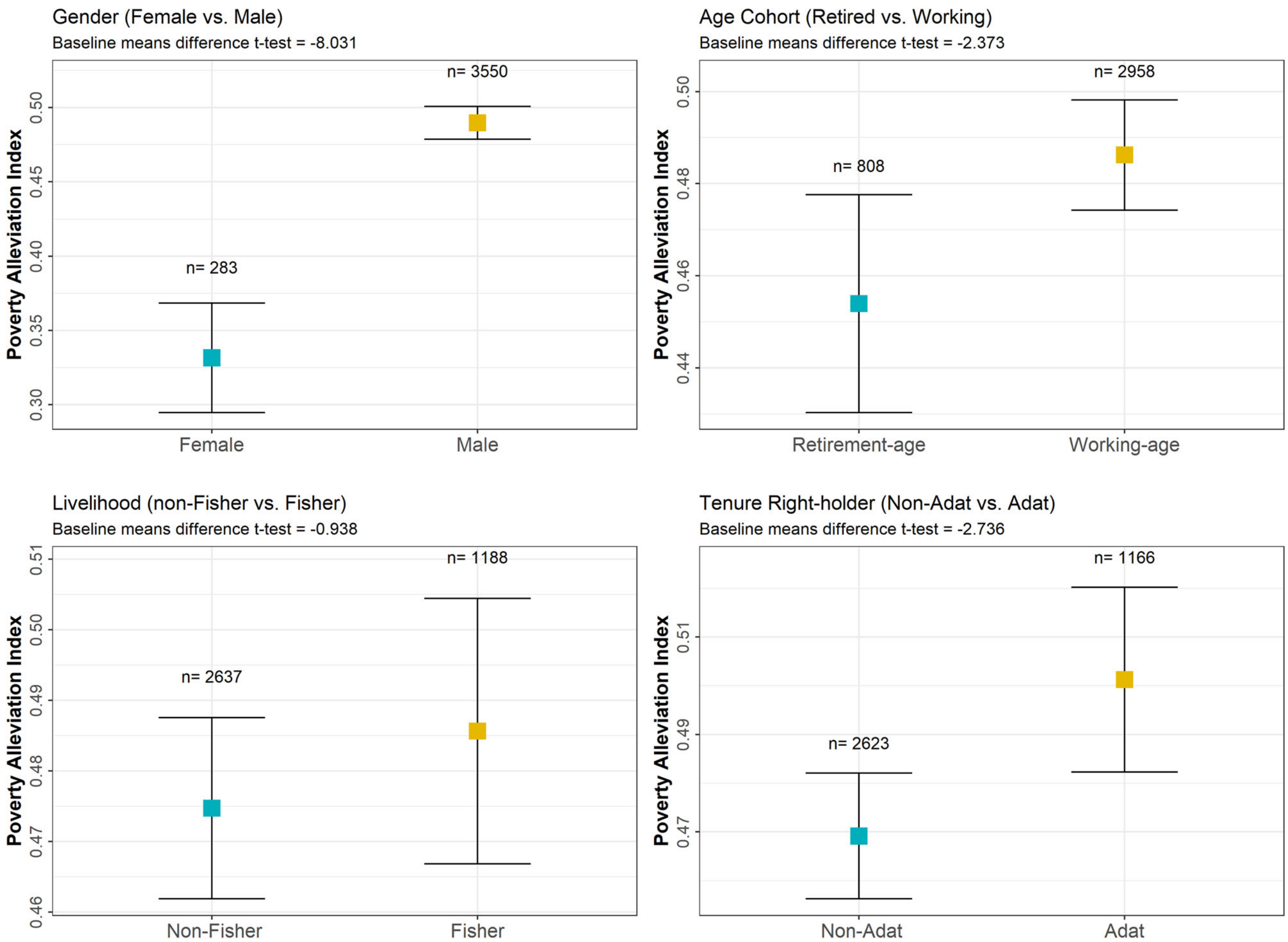

Fig. 2 | Baseline poverty alleviation (PCA index) across socioeconomic subgroups. Baseline poverty alleviation (PCA index) across subgroups defined by gender (upper-left panel), age cohort (upper-right panel), fishery livelihood (bottom-left panel), and tenure rights (bottom-right panel). Square dots represent subgroup means. Whiskers represent 95% confidence intervals. A higher index mean indicates greater poverty alleviation (or less poverty exposure). Sample size (*n*) corresponds to the number of respondents in each subgroup.

Table 4; Panels A and B). Refer to the estimated coefficient "*Post*", reflecting the average all-sample temporal change in outcome variables after controlling for both settlement- and household-level covariates. See "Econometric model" in "Methods" for further details. Specifically, the estimation result suggests that average material poverty in the studied area decreased by 2 to 4 percent, as reflected by the positive estimated changes in the poverty alleviation index (Panel A). Likewise, there was a seascape-wide average increase of between 6 and 12 percent in the likelihood that a household perceived economic stability or improvement over the study period (Panel B). The fact that there had been economic improvement in the broader seascapes is possibly linked to the continued success in the Indonesian government's effort to alleviate poverty in the country. According to the World Bank, the poverty rate in Indonesia halved from 24% in 1999 to 11.4% by early 2013[45]. With regard to MPA impacts, the result suggests statistically non-significant MPA treatment effect on poverty index and households' economic perception at the aggregate level (Supplementary Table 4; Panels A and B. Refer to the estimated DiD coefficient "*MPA X Post*").

We also assess MPA impact on poverty inequality. Here, we use Gini coefficients that measure the dispersion of poverty scores across households within a settlement, where a greater Gini score indicates a higher level of inequality in the distribution of households' exposure to poverty. Supplementary Figs. A4 and A5 visually elaborate on the use of this inequality measurement in our setting, showing the baseline inequality Lorenz curve and the histogram distribution of the Gini scores. The mean Gini coefficient of the poverty alleviation index in the dataset is 0.335, which is relatively consistent with Indonesia's overall Gini coefficient for income distribution estimated by the World Bank (0.381 in 2017). Model results suggest there is some evidence of a broad shrinking poverty gap in material well-being across households in the seascapes in the magnitude of 2–4 percentage points (Supplementary Table 4; Panel C). However, the MPA impact on poverty inequality is not statistically significant. Nonetheless, aggregated impact estimates may mask potential heterogeneity of impacts among subgroups.

Heterogeneous impact across social groups

While we observe non-significant *aggregate* MPA impact on economic well-being and inequality at the settlement level, we next investigate the disaggregated MPA effects across social groups. Two major results emerge. We find overwhelmingly non-significant MPA effects on households' tangible wealth (asset-based poverty index). This result suggests that the implementation of MPAs did not exacerbate or ameliorate material poverty or economic inequality between social groups. However, MPAs seem to have generated a *constraining* effect on households' subjective economic improvement, significantly so for female-headed and, to a lesser extent, for non-fishing households (Fig. 3; see also Supplementary Table 5). That is, the self-perceived improvement in economic well-being among households exposed to MPA in these social groups was slower compared to their counterfactuals after the MPA establishment.

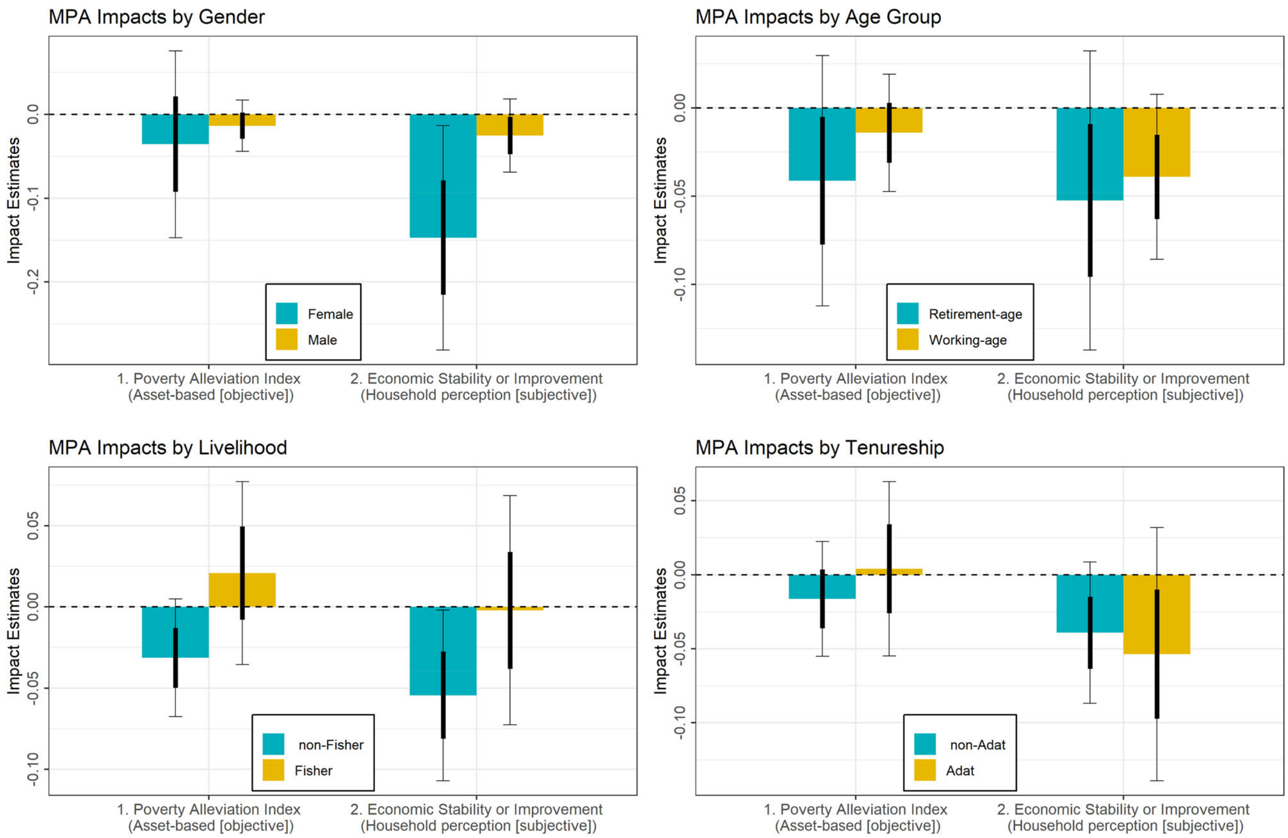

Fig. 3 | Distributional impact of MPAs across socioeconomic subgroups. Impacts are estimated from the difference-in-differences model in Eq. 1 for two economic-well-being outcome indicators: (1) poverty alleviation index and (2) household perception of economic stability or improvement. Bar heights illustrate estimated impact directions and magnitudes, with more positive values representing better economic well-being. Thick [thin] whiskers represent one-standard-error [95-percent] confidence intervals around the estimated average treatment effects (mean). Blue bars represent the more economically disadvantaged subgroup. Each subgroup-specific effect is estimated by comparing the treated and non-treated households belonging to the same social group. Sample size (*n*) corresponds to the number of respondents in each subgroup. The sample size (number of respondents) corresponding to the Asset-based well-being [Perceived well-being] regressions for female, male, retirement-age, working-age, non-fishers, fishers, non-Adat, and Adat groups are respectively 765 [804]; 8812 [9232]; 2158 [2327]; 7263 [7557]; 7006 [7413]; 2571 [2623]; 6843 [7064]; 2518 [2537].

While the introduction of MPAs can act as a potential stressor to the livelihood of some vulnerable coastal individuals[46,47], our findings suggest that MPAs in our study had negligible negative impacts on the objective poverty index. Studies have shown that the implementation of conservation interventions could serve as major livelihood shocks, especially to vulnerable resource-dependent groups in the short term[23,24,48]. In these cases, the loss of access or harvest rights to marine resources, potentially coupled with increased costs from displacement from ocean areas, leads to declines in income, food security, and other aspects of human well-being[8,49–52]. From this perspective, our finding of negligible negative impacts of MPAs on the tangible economic well-being (i.e., asset-based poverty) of disadvantaged groups can be taken as an encouraging outcome. The MPAs in this study were designed through lengthy consultation and involvement of the local community[53]. As such, it could be possible that this inclusive design process helped to ensure that the MPA would not have a negative impact on the affected communities.

On the other hand, the significant and negatively estimated impact of MPA establishment on females' perceived economic well-being is in line with existing evidence on both terrestrial and marine conservation and other development interventions, which have shown that women are more likely to be negatively impacted by livelihood disturbances[15,19,33,50,54–56]. Despite holding[57] important roles within rural fishing communities[55,56,58], women are often excluded from or under-represented in local decision-making processes[15,19,54,59,60]. This exclusion can lead to interventions that fail to account for disproportionate impacts on this marginalized group. Similarly, the negative impacts on perceived well-being in non-fisher households could be a result of the fact that MPA interventions often focus their attention on supporting marine resource users[15,21].

Moderating factors

Next, we examine how social inclusiveness—measured by the level of household participation in community groups in each settlement—moderates MPA's poverty impact. Within the conservation and common-pool resource literature, several studies indicate that a more organized and inclusive community is often more capable of enhancing participatory and transparent decision-making processes, and as a result promotes equitable distribution of conservation benefits[61,62], thereby reducing inequality[15,19,63]. Across all four social groups, it is evident that the impacts on perceived economic trends and inequality (difference in impacts between groups) are more prominent in communities where fewer group members participated in community groups (lower than median levels of participation; see "Methods" for further details) (Fig. 4). A profound negative impact on the perceived economic condition is particularly observed for female-headed households located in settlements where this group participated less at baseline, compared to those in high-participation settlements (Fig. 4).

The beneficial effect of community participation supports existing research on the importance of local social context, governance, and collective action in shaping conservation impacts[32,39,64]. There are

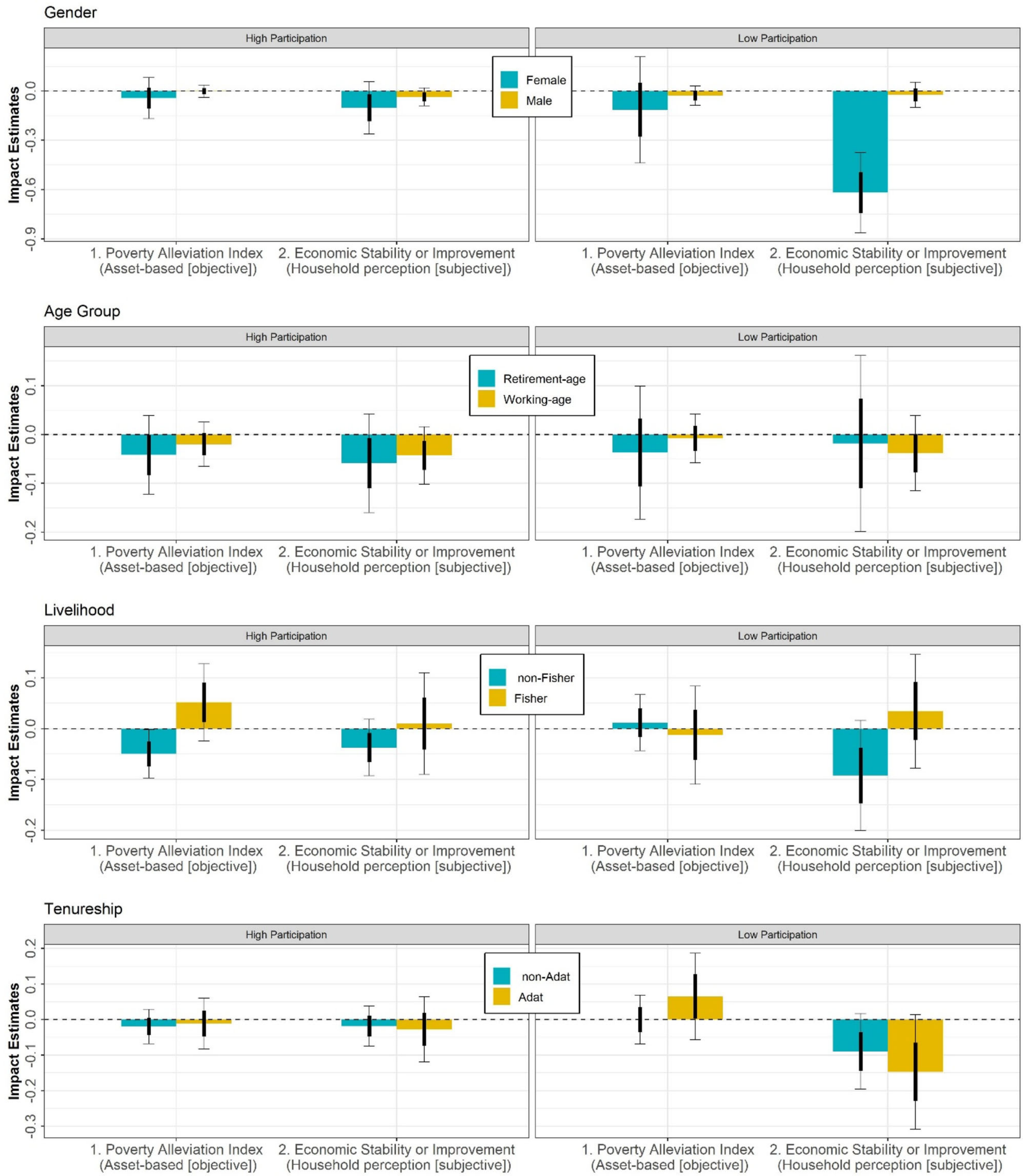

Fig. 4 | Distributional impact of MPAs across socioeconomic subgroups and levels of community participation. Distributional impacts are estimated separately for settlements with high (left panels) and low (right panels) levels of community participation. In each subgroup category, a settlement is classified as having a high (low) participation level if the baseline share of community group participation of the more economically disadvantaged subgroup (blue color) is above (below) its MPA's median. Bar heights illustrate the estimated impact directions and magnitudes, with more positive values representing greater poverty alleviation or a more positive perception of economic trend over the previous year for the poverty alleviation index and perception of economic trend, respectively. Thick [thin] whiskers represent one-standard-error [95-percent] confidence intervals around the estimated average treatment effects (mean). Blue bars represent the more economically disadvantaged subgroup. Each subgroup-specific effect is estimated by comparing the treated and non-treated households belonging to the same social group. Sample size (*n*) corresponds to the number of respondents in each subgroup. The sample size (number of respondents) corresponding to the Asset-based well-being [Perceived well-being] regressions for female, male, retirement-age, working-age, non-fishers, fishers, non-Adat, and Adat groups are respectively 765 [804]; 8812 [9232]; 2158 [2327]; 7263 [7557]; 7006 [7413]; 2571 [2623]; 6843 [7064]; 2518 [2537].

 https://doi.org/10.1038/s41467-026-69081-0

many potential mechanisms behind the relationship between community participation and perceived economic well-being. High community group participation could be an indicator of greater social cohesion and collective action. Community groups could be acting as a channel through which information is shared between otherwise isolated individuals. More substantively, greater community participation could also act as a social safety net, providing women with the social or other capitals necessary to adapt to potentially negative changes that stem from MPA establishment. Other studies have shown that belonging to a community group increases women's social capital through the processes of trust and reciprocity, which can translate to easier access to meaningful livelihood resources and help overcome negative short-term economic shocks, even if these resources are not easily translatable into material economic well-being[65] (Basurto et al.). At the same time, community group participation could facilitate greater self-determination and collective action, which allows them to actively participate in decision-making and lobby for fair distribution of benefits and burdens[62,66]. If so, this finding contributes to empirical evidence on the benefits of a social environment that fosters collective action, inclusion, and social mobilization[48,49,51,62,67–69] and corroborates the calls for a fair representation of vulnerable groups to ensure that they can access adequate community-level decision-making fora and resources[23,31,70]. Within a traditionally patriarchal society, such representation and support would be critical for female household heads in rural eastern Indonesia who are often widowed and experience great financial and social hardships[28].

Policy implications and future research

While much evidence exists on the impacts of MPAs on marine biodiversity, research on their impacts on resource-dependent coastal communities and how those impacts are distributed across dimensions of human well-being and social groups is more limited. Exploring a comprehensive, multi-wave survey dataset that covers over 10,000 households in coastal eastern Indonesia, our paper is one of the limited quantitative studies that contribute to the understanding of the distribution of multi-dimensional social impacts of MPAs, thereby providing insights on a fundamental aspect of MPA effectiveness: equitable conservation[71].

The evidence presented in this analysis has several important policy and research implications. First, like many other environmental policies, a protected-area initiative can have differential impacts on human well-being across various social groups. Second, MPA impacts are likely context dependent: restricting resource extraction in itself does not universally guarantee positive or negative social outcomes, but its effectiveness likely depends on various underlying contextual factors and the dimensions of well-being being considered. Although we find no significant impacts of the community-based MPA intervention on tangible well-being or inequality measured by households' material-asset ownership, MPAs might have served as a factor constraining the positive perception of the economic improvement of certain social groups, most notably female-headed households. Therefore, considerations must carefully take into account the diversity of potentially affected groups during the MPA design and implementation processes. Third, and relatedly, fostering social inclusiveness through inclusive planning processes (as done within many of the study MPAs) or community participation may mitigate expected short-term negative shocks from MPAs, such as an exacerbation of observed or perceived economic inequality. Our result suggests that promoting a higher level of community participation among marginalized groups, such as women, may serve as a beneficial buffer against potential livelihood stressors they would experience from MPA establishment. Given the potential role of community participation in moderating constraining effects, further research should seek to elucidate the mechanisms through which participation helps disadvantaged groups absorb potential short-term shocks, perceived or otherwise, that MPA or other types of interventions might introduce to their livelihoods. Lastly, our study demonstrates the benefits of applying robust impact evaluation methods to disaggregated monitoring data, which offer insights to the vastly understudied area of social equality and environmental policies, such as PAs.

Methods

Study context

This paper leverages the depth of a long-term, household-level social monitoring dataset conducted in the BHS and SBS—a seascape being bio-geographically defined as a network of MPAs—in eastern Indonesia. Baseline surveys for each MPA occurred in 2010 (Mayalibit and Cenderawasih), 2011 (Kofiau and Misool), 2012 (Kaimana and Dampier), 2014 (Selat Pantar and Flores Timur), and 2016 (Kei Kecil and Koon). Mayalibit, Cenderawasih, Kaimana, Kofiau, Dampier, and Misool belong to the BHS. Selat Pantar, Flores Timur, Kei Kecil, and Koon belong to the SBS. Each survey round for BHS MPAs was conducted 2 years apart. Each survey round for SBS MPAs was conducted 3 years apart. Supplementary Table 1 presents sampling characteristics in more detail.

MPAs in the BHS and SBS seascapes are characterized by distinct approaches to design and governance. In BHS, MPA design was predominantly community-led, initiated through customary declarations and supported by NGOs, with boundaries often aligned with traditional marine tenure areas. These were later formalized by the provincial ("*provinsi*"; first division) or regency ("*kapubaten*"; second division) governments and recognized nationally. Governance in BHS is characterized by co-management structures involving local communities, provincial agencies (e.g., UPTD-BLUD), and national ministries[41,72]. In contrast, SBS MPAs were largely designed through a top-down process led by national ministries (MMAF and MoEF), using biophysical and habitat data to delineate boundaries. Governance in SBS is more centralized, with management responsibilities transitioning from regency to provincial governments post-2017[28,73]. Given the differences in legal jurisdiction, management maturity, and local governance practices, MPA rules related to the level of restriction and enforcement on fishing gear and target species also vary significantly across MPAs in the two seascapes.

In our regression analysis, we account for the differences in MPA design origin and governance structure across the studied MPAs with the inclusion of MPA-specific fixed effects. Essentially, our model strictly estimates the average treatment effect of MPA establishment by comparing the temporal variation (before- vs. after-intervention) in the outcomes of treated and control individuals located *within* the same MPA.

Survey design

Our survey method uses a coarse-matching procedure to identify settlements outside a specific MPA boundary with a high probability of containing a similar socio-demographic composition of households to those within that MPA prior to the MPA intervention. Specifically, we identified a comparable group of counterfactual settlements (i.e., the control group) with residents that were similar to those within treated settlements in each MPA based on four pre-treatment social dimensions:

- *Distance to market*—the proximity (Euclidean distance) between the settlement and the nearest local market, defined by local experts as the place that the majority of households in the settlement go to sell their fish catch. Distance to market is a well-documented bias in the placement of terrestrial PAs, with regions in close proximity to major population centers less likely to be designated for conservation[74]. Market access is associated with increased economic activity and thus wealth. It also increases opportunities to sell catch and thus structures fishing activity, influencing both fishing pressure and the gear choice by fishers[75].

Evidence from the Solomon Islands suggests proximity to market correlates with depleted fish assemblages and biomass[75], both frequently used as outcome metrics to assess the ecological impact of MPAs.

- *Predominant occupation*—the dependence of communities on marine resources, computed as the share of households having fishing as their primary livelihood activity. The dependence of communities on marine resources have been shown to be a likely significant mediator of the social impacts of MPAs[76,77]. Households with high dependence on marine resources are more likely to be impacted by the reallocation of resource rights linked to MPA establishment[13].
- *Political jurisdiction*—decision-making regarding MPA establishment and management may vary between jurisdictions. We exact-match treatment and control settlements from the same regency (Kabupaten) and province (Provinsi). Political jurisdiction may affect the likelihood of MPA establishment (Fox et al.[38]), and management capacity may vary across jurisdictions.
- *Ethnic composition*—the composition of major ethnic groups in the settlement, measured as the household share of the most dominant ethnic group residing in the settlement. We combine secondary data and expert knowledge to classify each settlement using this typology. Social structure influences the probability of collective action and self-governance, as well as the characteristics of governance[62]. Groups with a greater degree of divisibility may adopt different strategies for collective action than more homogeneous groups[78]. Social structure may also shape the type of MPA established, with decentralized structures more likely to emerge where the probability of local collective action is high[78]. There is evidence that social cohesion correlates strongly with effective fisheries management[79]. Marine resource governance in Papua is territorial, with defined local groups possessing customary tenure to marine resources[80]. Social structure, through its role in mediating collective action, may influence the strength of these customary systems.

Following the above, 10 MPA "clusters" were produced, comprising treated (MPA) and comparable untreated (neighboring non-MPA) settlements. Glew et al.[41] provides more detailed information on the study design.

In Fig. 1, settlements located inside MPA zones (124) constitute the treatment group. Comparable, coarsely matched settlements located outside MPA zones are neighboring villages constituting the counterfactual (control) group. The dataset covers 10,123 households in 180 settlements. There are two follow-up survey rounds (2 years apart) in each BHS settlement. There is one follow-up survey round in each SBS settlement (3 years from baseline surveys).

The period of official implementation in our setting refers to the year the MPA started receiving formal management and/or monitoring and enforcement, with two exceptions. The first applies to Cenderawasih MPA (BHS), which was established in 2002. We used a re-zoning exercise in 2010 as our window of opportunity for baseline survey and considered the redesigned MPA as the treatment. The second exception applies to Flores Timur MPA, where official MPA enforcement has not been formally established and thus unlikely to influence outcomes prior to monitoring. We refer to treatment status in this case when the MPA demarcation and zoning took place, and a baseline survey was conducted in 2013.

Variables formation

Social sub-groups. This analysis examines four social subgroups relevant to the existing conservation literature (see Supplementary for further details):

- Gender (male vs. female)—defined by the gender of the household heads
- Fishery livelihood (households employed in fishery vs. non-fishery occupations)—defined by whether the household relies on fishing as a primary, secondary, or tertiary livelihood
- Age cohort (retired vs. working-age)—defined by the age of the household head being greater or less than 65 years old
- Tenureship (Adat vs. non-Adat)—with the Adat households being identified as individuals holding premium tenure rights to marine resources. These are individuals who indicated that they have either: (1) personally made decisions about managing marine resources [the right to manage], (2) determined who could or could not enter marine areas [the right to exclude], or (3) personally sold or leased the right to harvest resources within a specified marine area [the right to transfer]. There could be a limited number of households holding the right to manage MPA who are technically non-Adat, but they often hold advanced social positions (leaders of community groups such as religious leaders, village leaders, youth leaders, women leaders, etc.) regardless. While those with the rights to exclude and transfer are strictly Adat, we define the Adat group as those with the rights to manage, exclude, and transfer marine resources (i.e., collective choice rights), as these individuals also have the power to determine how or whether others can use or access the resource[81].

Poverty alleviation index. This analysis follows an established economic development literature to construct an index of poverty alleviation, which is calculated from a PCA that integrates household asset ownership and cooking fuel usage. There are several reasons the poverty alleviation index is an appropriate measure of economic well-being in our study setting. First, in eastern Indonesia, many households in coastal communities are engaged in subsistence fisheries and small-scale or subsistence farming. Their income is subject to seasonal and non-seasonal variations to marine and agricultural conditions, which are often subject to external shocks[28,41]. Second, as with popular cases pertaining to the informal sector in developing countries, reported income under our study setting is likely an imperfect measure of economic well-being, as it fails to capture the non-cash economy and the importance of subsistence activities to sustain an individual or household. Third, household income measures are also likely missing or prone to potential accounting and recall biases[42]. Unlike income and consumption—the two most conventional measures of economic wealth—household asset ownership is less tied to payment types or subject to seasonal variation, making it a more stable indicator to measure poverty[44].

We follow the approach from Filmer and Pritchett[42] and Sahn and Stifel[43] to construct a poverty index for each household that consists of nine household asset components provided in the household survey (Supplementary Table 3 and Supplementary Fig. 1). The underlying components of the index are binary indicators of asset ownership, including whether the household owns at least any of one of the following assets: telephone, television, entertaining equipment, satellite dish, generator, bike, motorbike, car or truck, and boats. Given that the asset data were binary (i.e., equals 0 if the asset was not owned or biomass fuel used; equals 1 if the asset was owned or non-biomass fuel used), all values were on the same scale and thus did not need to be normalized. We constructed the PCA index using the *prcomp* package in R (v. 4.4.0), retaining the first principal component, which captured the greatest variance among the combination of asset ownership and cooking fuel usage factors. The factor coefficient scores—also known as factor loading—from the first component are used as the weights for each asset ownership variable, which are then combined into a single household-level index score. By design, the value of the index ranges from 0 to 1. Supplementary Table 3 and Supplementary Fig. 1, respectively, provide details of the asset weight structure and the explanatory relationship between each individual asset-ownership indicator with the principal component of poverty. Based on the default binary values, an index score of 1 indicates "no poverty": the household possesses at least one of each of the nine asset components and uses a non-biomass fuel type for cooking (gas or oil). In contrast, an index score of 0 indicates "absolute poverty": the household owns none of any of the asset components and cooks with biomass fuel. Supplementary Fig. 2 plots the histogram distribution of the index in the sample.

It is noted that, due to the reasons discussed, our social monitoring survey does not collect information on households' income and consumption. To investigate how well the PCA index measures poverty alleviation, we follow a conventional approach in the literature to look at the relationship of the index with two benchmark indicators of household welfare: food security and educational attainment[42,43].

The Food Security index (FS) is constructed from the health indicators in the health module of the social monitoring questionnaire (i.e., the same household survey) and is benchmarked from the USDA Household Food Security Scale[82]. Households are classified as: (a) Food insecure with hunger (FS from 0 to 1.56)—"food intake for household members has been reduced to an extent that implies that household members have repeatedly experienced the physical sensation of hunger"; (b) Food insecure without hunger (FS from 1.56 to 4.02)—"food insecurity is evident in household members' concerns about adequacy of the household food supply and in adjustments to household food management, including reduced quality of food and increased unusual coping patterns. Little or no reduction in members' food intake is reported"; and (c) Food secure (FS from 4.02 to 6.06)—"household shows no or minimal evidence of food insecurity."

- The educational level of the household head is a categorical variable defined as 1 = "No or Below primary school education"; 2 = "Primary school education"; 3 = "Junior secondary school education"; 4 = "Senior secondary school education"; 5 = "Higher or further education."

A significant and positive relationship between food security and educational attainment, and our poverty-reduction metric, is observed, providing additional support for the utility of the asset-based measure of economic welfare.

Perceived economic well-being. The majority of existing studies on the socioeconomic impacts of MPAs (and other biodiversity conservation interventions) either focus solely on identifying subjective, self-stated responses of human well-being through qualitative analyses[15,19,56,63,67,83], or, more limitedly, measuring objective economic outcomes through quantitative analyses where accounting data are available[68,84]. In this analysis, we assess both dimensions. In addition to examining an objective indicator of economic well-being (i.e., poverty alleviation index), we derive a subjective indicator of households' economic well-being, using respondents' perception of changes in economic status that they experienced in the last year (*"How has the economic condition of your household changed over the past 12 months?"*). We then recode each of the categorical responses into a binary indicator that indicates a subjective "economic stability or improvement," which we use as a measure of a household's *perceived* poverty reduction. The mechanical design is to ensure that the impact direction of this measure would be harmonized with the asset-based poverty alleviation index, i.e., a *larger* value would indicate *positive* economic change, both subjectively and objectively. Another advantageous feature of our dual measures is that they complement each other in capturing MPA impacts on both household's economic well-being status (with the static asset-based poverty index) and trend (with the perceived direction of change in well-being).

Econometric model

To assess the impacts of MPA intervention on different societal groups, we employ a causal inference approach in the form of a DiD estimation—a quasi-experimental technique popular in the literature of impact evaluation. Essentially, this method compares the differences in the average of household-level outcomes over time (i.e., between the pre- and post-intervention periods) across treated and counterfactual settlements, while accounting for both fixed and varying factors potentially correlated with both treatment status and changes in the dependent variables.

Econometrically, the DiD approach takes a regression form:

$$y_{ist} = \alpha_0 + \alpha_1 MPA_s + \alpha_2 Post_t + \boldsymbol{\alpha_3} MPA_s \times Post_t + \alpha_4 X_{ist} + \lambda_s + \sum_{T=2010}^{2017} T + \varepsilon_{ist} \tag{1}$$

where y_{ist} represents two main household-level well-being outcomes employed in the analysis—(1) asset-based poverty index (objective economic well-being) and (2) change in household's perceived economic condition (subjective measure). The subscripts refer to household i located in settlement s in period t, with t being an MPA-specific temporal indicator denoting the survey period relative to baseline (e.g., $t = 0$ indicating baseline survey round, $t = 1$ indicating the first post-line survey round, and $t = 2$ indicating the second post-line survey round). MPA_s is a binary term indicating that the settlement is located within a protected zone (i.e., being "treated"). $Post_t$ is a binary variable indicating post-baseline periods specific to each of the 10 MPAs, taking the value of 0 for baseline survey waves, and 1 for post-implementation waves. X_{ist} is a vector of household-level covariates: (i) household head's age, (ii) gender, (iii) membership in the dominant local ethnicity, (iv) highest level of education obtained, (v) number of children, and (vi) years of residence; λ_s and $\sum_{T=2010}^{2017} T$ respectively represent MPA-specific and calendar-year fixed effects, the inclusions of which account for both time-invariant confounders at the MPA level and region-wide factors common to all settlements in a particular year (e.g., broad-based macroeconomic and environmental conditions, such as fluctuation in fuel prices or the occurrence of natural disasters). The inclusion of λ_s essentially absorbs the singular term MPA_s in the model. Finally, ε_{ist} represents household-level idiosyncratic error terms clustered at the settlement level. To study heterogeneous impacts, we estimate the DiD model separately for each subgroup in our analysis. Under satisfying validity assumptions that we discuss in detail in the Supplementary document, the estimated coefficient $\boldsymbol{\alpha_3}$ associated with the interaction term $MPA_s \times Post_t$ illustrates the MPA treatment effect on household-level well-being outcomes.

A derivative specification of our main household-level DiD model is a settlement-level approach:

$$y_{st} = \alpha'_0 + \alpha'_1 x MPA_s + \alpha'_2 Post_t + \boldsymbol{\alpha'_3} MPA_s \times Post_t + \alpha'_4 X_{st} + \lambda_s + \sum_{T=2010}^{2017} T + \varepsilon_{st} \tag{2}$$

where everything remains the same as in Eq. (1), except for the conversion of the dependent variable (y_{st}) and predictor covariates (X_{st}) from the household to settlement level. Specifically, vector X_{st} includes the baseline settlement-level fishery component (%), average time to market (hours), the composition of customary governance (%), and the settlement's geographic location (latitude and longitude degrees).

In the analysis, we estimate Eq. 2 with three main dependent variables: (i) the settlement's mean poverty alleviation index (objective measure), (ii) mean percentage of households reporting positive economic perception (subjective measure), and (iii) the "inequality" Gini measure of poverty. Detailed empirical results are presented in Supplementary Table 4.

To detect the overall poverty trend in the monitoring regions, we focus on the estimated coefficients of indicator $Post_{st}$, which reflects the average seascape-wide conditions after MPA establishment relative to the baseline (i.e., common trend across both the treatment and control groups).

Classifying subgroups' community participation

For each subgroup category, we calculate the number of social and community groups that household heads participated in the year before MPA implementation. We derive a median participation level (i.e., the median number of community groups a household participating in) for each MPA. We subsequently divide settlements in each MPA into two groups based on whether average community group participation by the more economically disadvantaged subgroup (i.e., female-head, non-Adat, retired, and non-fishers), was greater or lower (high and low participation settlements, respectively) than the median value for that MPA.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

This study was conducted in accordance with the guidelines of the Duke University Institutional Review Board (IRB # 2023-0007) for the analysis of existing data. The original data were collected following best practice ethical guidelines regarding research conduct (National Academy of Sciences 1995; American Anthropological Association 1998). For more information on data collection, see the survey manual (Glew et al.[41]). Data requests should be made to the corresponding and senior authors.

Code availability

The R code used in the data analysis and to generate figures is available from the corresponding author upon request.

References

1. Barnes, M., Glew, L., Craigie, I. D. & Wyborn, C. Aichi Targets: protect biodiversity, not just area. *Nature* **526**, 195 (2015).
2. CBD. *Kunming-Montreal Global Biodiversity Framework* (Convention on Biological Diversity, 2022).
3. UN. *United Nations Sustainable Development Goal 14: Conserve and Sustainably Use the Oceans, Seas and Marine Resources* (UN, 2016).
4. Agrawal, A. Matching and mechanisms in protected area and poverty alleviation research. *Proc. Natl. Acad. Sci. USA* **111**, 3909–3910 (2014).
5. Ferraro, P. J. et al. More strictly protected areas are not necessarily more protective: evidence from Bolivia, Costa Rica, Indonesia, and Thailand. *Environ. Res. Lett.* **8**, 025011 (2013).
6. Pfaff, A. et al. Governance, location and avoided deforestation from protected areas: greater restrictions can have lower impact, due to differences in location. *World Dev*. **55**, 7–20 (2014).
7. Ban, N. C. et al. Well-being outcomes of marine protected areas. *Nat. Sustain.* **2**, 524–532 (2019).
8. Gill, D. A. et al. Social synergies, tradeoffs, and equity in marine conservation impacts. *Annu. Rev. Environ. Resour.* **44**, 1–26 (2019).
9. McKinnon, M. C. et al. What are the effects of nature conservation on human well-being? A systematic map of empirical evidence from developing countries. *Environ. Evid.* **5**, 8 (2016).
10. UNEP-WCMC, IUCN, and NGS. *Protected Planet Report 2018* (United Nations Environment Programme (UNEP-WCMC), International Union for Conservation of Nature (IUCN), and National Geographic Society (NGS), 2018).
11. Mascia, M. B. et al. An appeal for a code of conduct for marine conservation. *Mar. Policy* **81**, 411–418 (2017).
12. Ferraro, P. J., Sanchirico, J. N. & Smith, M. D. Causal inference in coupled human and natural systems. *Proc. Natl. Acad. Sci. USA* **116**, 5311–5318 (2019).
13. Mascia, M. B., Claus, C. A. & Naidoo, R. Impacts of marine protected areas on fishing communities. *Conserv. Biol.* **24**, 1424–1429 (2010).
14. Smallhorn-West, P. F., Weeks, R., Gurney, G. & Pressey, R. L. Ecological and socioeconomic impacts of marine protected areas in the South Pacific: assessing the evidence base. *Biodivers. Conserv*. **29**, 349–380 (2020).
15. Mahajan, S. L. & Daw, T. Perceptions of ecosystem services and benefits to human well-being from community-based marine protected areas in Kenya. *Mar. Policy* **74**, 108–119 (2016).
16. Menezes, A., Eide, A. & Raakjær, J. Moving out of poverty: conditions for wealth creation in small-scale fisheries in Mozambique. in *Poverty Mosaics: Realities and Prospects in Small-Scale Fisheries* (eds Jentoft, S. & Eide, A.) 407–426 (Springer Netherlands, 2011).
17. Ward, C., Holmes, G. & Stringer, L. Perceived barriers to and drivers of community participation in protected-area governance. *Conserv. Biol.* **32**, 437–446 (2018).
18. Christie, P. Marine protected areas as biological successes and social failures in Southeast Asia. *Am. Fish. Soc.* **42**, 155–164 (2004).
19. Gustavsson, M., Lindström, L., Jiddawi, N. S. & de la Torre-Castro, M. Procedural and distributive justice in a community-based managed marine protected area in Zanzibar, Tanzania. *Mar. Policy* **46**, 91–100 (2014).
20. Baker, D. et al. Relationships matter: assessing the impacts of a marine protected area on human wellbeing and relational values in Southern Tanzania. *Front. Mar. Sci.* **8**, 673045 (2021).
21. Gurney, G. G. et al. Integrated conservation and development: evaluating a community-based marine protected area project for equality of socioeconomic impacts. *Philos. Trans. R. Soc. B Biol. Sci.* **370**, 20140277 (2015).
22. Persha, L. & Andersson, K. Elite capture risk and mitigation in decentralized forest governance regimes. *Glob. Environ. Change* **24**, 265–276 (2014).
23. Bennett, N. J. et al. An appeal for a code of conduct for marine conservation. *Mar. Policy* **81**, 411–418 (2017).
24. Cohen, P. J. et al. Securing a just space for small-scale fisheries in the blue economy. *Front. Mar. Sci.* **6**, 171 (2019).
25. Barbier, E. B. Climate change impacts on rural poverty in low-elevation coastal zones. *Estuar. Coast. Shelf Sci.* **165**, A1–A13 (2015).
26. Cahaya, A. Fishermen community in the coastal area: a note from Indonesian poor family. *Procedia Econ. Financ.* **26**, 29–33 (2015).
27. Whittingham, E., Campbell, J. & Townsley, P. *Poverty and Reefs: A Global Overview* (DFID–IMM–IOC/UNESCO, 2003).
28. Setyawan, E. et al. *State of the Sunda Banda Seascape Marine Protected Area Network – 2017, Summary Report* (World Wildlife Fund, University of Pattimura, Wildlife Conservation Society, Coral Triangle Centre, RARE, 2018).
29. Mangubhai, S. & Lawless, S. Exploring gender inclusion in small-scale fisheries management and development in Melanesia. *Mar. Policy* **123**, 104287 (2021).
30. Giakoumi, S. et al. Revisiting "success" and "failure" of marine protected areas: a conservation scientist perspective. *Front. Mar. Sci.* **5**, 223 (2018).
31. IIED. *Advancing Equity in Protected Area Conservation* (International Institute for Environment and Development (IIED), 2016).
32. Mizrahi, M., Diedrich, A., Weeks, R. & Pressey, R. L. A systematic review of the socioeconomic factors that influence how marine protected areas impact ecosystems and livelihoods. *Soc. Nat. Resour.* **32**, 4–20 (2018).
33. Dawson, N. & Martin, A. Assessing the contribution of ecosystem services to human well-being: a disaggregated study in Western Rwanda. *Ecol. Econ.* **117**, 62–72 (2015).

34. Friedman, R. S. et al. How just and just how? A systematic review of social equity in conservation research. *Environ. Res. Lett.* **13**, 053001 (2018).
35. Law, E. A. et al. Equity trade-offs in conservation decision making. *Conserv. Biol.* **32**, 294–303 (2018).
36. Woodhouse, E., Claire Bedelian, N. D. & Barnes, P. Social impacts of protected areas: exploring evidence of trade-offs and synergies. in *Ecosystem Services and Poverty Alleviation* (eds Schreckenberg, K., Mace, G. & Poudyal, M.) 222–240 (Routledge, 2018).
37. Althor, G. et al. Does the social equitability of community- and incentive-based conservation interventions in non-OECD countries affect human well-being? A systematic review protocol. *Environ. Evid.* **5**, 1–11 (2016).
38. Fox, H. E. et al. Explaining global patterns and trends in marine protected area (MPA) development. *Mar. Policy* **36**, 1131–1138 (2012).
39. Agrawal, A. & Chhatre, A. Against mono-consequentialism: multiple outcomes and their drivers in social-ecological systems. *Glob. Environ. Change* **21**, 1–3 (2011).
40. Coad, L., Campbell, A., Miles, L. & Humphries, K. *The Costs and Benefits of Forest Protected Areas for Local Livelihoods: A Review of the Current Literature* (UNEP World Conservation Monitoring Centre, 2008).
41. Glew, L., Mascia, M. B. & Pakiding, F. *Solving the Mystery of Marine Protected Area Performance: Monitoring Social Impacts: Field Manual v1.0* (World Wildlife Fund US, 2012).
42. Filmer, D. & Pritchett, L. Estimating wealth effects without expenditure data-or tears: an application to educational enrollments in states of India. *Demography* **38**, 115–132 (2001).
43. Sahn, D. & Stifel, D. Exploring alternative measures of welfare in the absence of expenditure data. *Rev. Income Wealth* **49**, 463–489 (2003).
44. Rustein, S. O. & Johnson, K. *DHS Comparative Report: The DHS Wealth Index* (ORC Macro, 2004).
45. World Bank. *Indonesia Economic Quarterly* (World Bank, 2014).
46. Brondo, K. V. & Bown, N. Neoliberal conservation, garifuna territorial rights and resource management in the Cayos Cochinos Marine Protected Area. *Conserv. Soc.* **9**, 91–105 (2011).
47. Himes, A. H. Small-Scale Sicilian Fisheries: opinions of artisanal fishers and sociocultural effects in two MPA case studies. *Coast. Manag.* **31**, 389–408 (2003).
48. Dobrzynski, T. J. & Nicholson, E. E. User group perceptions of the short-term impacts of marine reserves in Key West. In *Proc. Ninth International Coral Reef Symposium* (eds Kasim Moosa, M. K. et al.) 759–764 (Indonesian Institute of Sciences and State Ministry for Environment, 2003).
49. Hattam, C. E., Mangi, S. C., Gall, S. C. & Rodwell, L. D. Social impacts of a temperate fisheries closure: understanding stakeholders' views. *Mar. Policy* **45**, 269–278 (2014).
50. Kamat, V. The ocean is our farm: marine conservation, food insecurity, and social suffering in Southeastern Tanzania. *Hum. Organ.* **73**, 289–298 (2014).
51. Kamat, V. R. Dispossession and disenchantment: the micropolitics of marine conservation in Southeastern Tanzania. *Mar. Policy* **88**, 261–268 (2018).
52. Mascia, M. B. & Claus, C. A. A property rights approach to understanding human displacement from protected areas: the case of marine protected areas. *Conserv. Biol.* **23**, 16–23 (2009).
53. Mangubhai, S. et al. Explicitly incorporating socioeconomic criteria and data into marine protected area zoning. *Ocean Coast. Manag.* **116**, 523–529 (2015).
54. Bandiaky, S. Gender inequality in malidino biodiversity community-based reserve, Senegal: political parties and the 'Village Approach'. *Conserv. Soc.* **6**, 62–73 (2008).
55. Britton, E. & Coulthard, S. Assessing the social wellbeing of Northern Ireland's fishing society using a three-dimensional approach. *Mar. Policy* **37**, 28–36 (2013).
56. Weigel, J. Y. et al. Assessing economic effects of a marine protected area on fishing households. A Thai case study. *Fish. Res.* **161**, 64–76 (2015).
57. Harper, S. et al. Valuing Invisible Catches: Estimating the Global Contribution by Women to Small-Scale Marine Capture Fisheries Production. *PLOS One* **15**, e0228912 (2020).
58. Kleiber, D., Harris, L. M. & Vincent, A. C. J. Gender and small-scale fisheries: a case for counting women and beyond. *Fish Fish.* **16**, 547–562 (2015).
59. Matsue, N., Daw, T. & Garrett, L. Women fish traders on the Kenyan coast: livelihoods, bargaining power, and participation in management. *Coast. Manag.* **42**, 531–554 (2014).
60. Rohe, J., Schlüter, A. & Ferse, S. C. A. A gender lens on women's harvesting activities and interactions with local marine governance in a South Pacific fishing community. *Marit. Stud.* **17**, 155–162 (2018).
61. Hayes, T. & Murtinho, F. Communal governance, equity and payment for ecosystem services. *Land Use Policy* **79**, 123–136 (2018).
62. Ostrom, E. *Governing the Commons: The Evolution of Institutions for Collective Action* (Cambridge University Press, 1990).
63. Islam, M. M. et al. Fishers' perceptions of the performance of Hilsa Shad (Tenualosa ilisha) sanctuaries in Bangladesh. *Ocean Coast. Manag.* **130**, 309–316 (2016).
64. Brooks, J. S., Waylen, K. A. & Borgerhoff Mulder, M. How national context, project design, and local community characteristics influence success in community-based conservation projects. *Proc. Natl. Acad. Sci. USA* **109**, 21265–21270 (2012).
65. Basurto, X. et al. Cooperative and noncooperative strategies for small-scale fisheries' self-governance in the Globalization Era: implications for conservation. *Ecol. Soc.* **18**, 38 (2013).
66. McDermott, M., Mahanty, S. & Schreckenberg, K. Examining equity: a multidimensional framework for assessing equity in payments for ecosystem services. *Environ. Sci. Policy* **33**, 416–427 (2013).
67. Bennett, N. J. & Philip, D. From measuring outcomes to providing inputs: governance, management, and local development for more effective marine protected areas. *Mar. Policy* **50**, 96–110 (2014).
68. McNally, C. G., Uchida, E. & Gold, A. J. The effect of a protected area on the tradeoffs between short-run and long-run benefits from mangrove ecosystems. *Proc. Natl. Acad. Sci. USA* **108**, 13945–13950 (2011).
69. Smith, M. D., Zhang, J. & Coleman, F. C. Effectiveness of marine reserves for large-scale fisheries management. *Can. J. Fish. Aquat. Sci.* **63**, 153–164 (2006).
70. Maharjan, M. R. et al. *Improving the Benefits to the Poor from Community Forestry in the Churia Region of Nepal* Vol. 11 (International Forestry Review, 2009).
71. IUCN. *Applying IUCN's Global Conservation Standards to Marine Protected Areas* (International Union for Conservation of Nature, 2018).
72. Purwanto et al. The Bird's Head Seascape Marine Protected Area Network—preventing biodiversity and ecosystem service loss amidst rapid change in Papua, Indonesia. *Conserv. Sci. Pract.* **3**, e393 (2021).
73. Estradivari et al. Marine conservation in the Sunda Banda Seascape, Indonesia. *Mar. Policy* **138**, 104994 (2022).
74. Joppa, L. N. & Pfaff, A. Global protected area impacts. *Proc. R. Soc. B Biol. Sci.* **278**, 1633–1638 (2011).
75. Brewer, T. D., Cinner, J. E., Fisher, R., Green, A. & Wilson, S. K. Market access, population density, and socioeconomic development explain diversity and functional group biomass of coral reef fish assemblages. *Glob. Environ. Change* **22**, 399–406 (2012).
76. Pollnac, R. et al. Marine reserves as linked social-ecological systems. *Proc. Natl. Acad. Sci. USA* **107**, 18262–18265 (2010).

77. Smith, M. D., Lynham, J., Sanchirico, J. N. & Wilson, J. A. Political economy of marine reserves: understanding the role of opportunity costs. *Proc. Natl. Acad. Sci. USA* **107**, 18300–18305 (2010).
78. Taylor, M. *The possibility of Cooperation* (Cambridge University Press, 1987).
79. Gutierrez, N. L., Hilborn, R. & Defeo, O. Leadership, social capital and incentives promote successful fisheries. *Nature* **470**, 386–389 (2011).
80. Cinner, J. Socioeconomic factors influencing customary marine tenure in the Indo-Pacific. *Ecol. Soc.* **10**, 36 (2005).
81. Schlager, E. & Ostrom, E. Property-rights regimes and natural resources: a conceptual analysis. *Land Econ.* **68**, 249–262 (1992).
82. Bickel, G., Nord, M., Price, C., Hamilton, W. & Cook, J. *Guide to Measuring Household Food Security, Revised 2000* (U.S. Department of Agriculture, Food and Nutrition Service, 2000).
83. Voyer, M., Gladstone, W. & Goodall, H. Understanding marine park opposition: the relationship between social impacts, environmental knowledge and motivation to fish. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **24**, 441–462 (2014).
84. Svensson, P., Rodwell, L. D. & Attrill, M. J. The perceptions of local fishermen towards a hotel-managed marine reserve in Vietnam. *Ocean Coast. Manag.* **53**, 114–122 (2010).

Acknowledgements

This research project, including the household surveys and data analysis in the Bird's Head Seascape and Sunda Banda Seascape in Indonesia, was supported by funded programs and research grants from The Lucile and Packard Foundation, Walton Family Foundation, and Margaret A. Cargill Philanthropies. The authors are grateful to all colleagues and counterparts from WWF-US, WWF-Indonesia, Nusa Tenggara Timur Provincial Government, Maluku Provincial Government, Universitas Papua, Universitas Nusa Cendana, Universitas Kristen Artha Wacana, Politeknik Pertanian Negeri Kupang, Universitas Pattimura, Conservation International, and The Nature Conservancy offices both in the USA and in Indonesia, the Cenderawasih National Park, the Indonesian National Park Service, and Duke University Marine Lab for helpful collaborations and advice. Le acknowledges research support from the World Wildlife Fund-U.S. and Duke University. The content is solely the responsibility of the authors and does not necessarily represent the official views of any of the above institutions. Last but not least, the authors would like to thank the dozens of enumerators and field coordinators who contributed to data collection and compilation, and the respondents from the settlements who assisted the teams and answered the questions, enabling the world to learn from their experiences.

Author contributions

M.B.M., F.P., and L.G. conceived the original social monitoring program; D.T.L., G.N.A., K.C., L.G., M.B.M., F.P., and D.G. designed the current study; M.B.M., F.P., and L.G. developed the research instruments and protocols; I.R.A., E., M.E.L., D.M., N.K.S.P., K.E.S., L.G., M.B.M., and F.P. acquired field data; D.T.L., I.R.A., E., P.M.M., H.N., N.R.T., F.P., and D.G. analyzed data; D.T.L., I.R.A., D.M., K.E.S., F.P., L.G., M.B.M, and D.G. interpreted data; and D.T.L., G.N.A., K.C., R.R., L.G., M.B.M., and D.G wrote or substantively revised the paper.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41467-026-69081-0.

Correspondence and requests for materials should be addressed to Duong Trung Le.

Peer review information *Nature Communications* thanks Kate Schreckenberg and the other, anonymous, reviewer(s) for their contribution to the peer review of this work. A peer review file is available.