Distributional Effects of Marine Conservation on Coastal Livelihoods in Eastern Indonesia

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Supplementary Information

I. SUPPLEMENTARY DISCUSSION

Covariates description

Supplementary Table 2 presents baseline descriptive statistics of the main socioeconomic characteristics of surveyed households. The mean household poverty alleviation index score at baseline is around 0.5. Across the seascapes, approximately a quarter of households perceived a stable or improved economic condition over the previous year. An average family in the sample had 2.5 children and had lived in the same community for 32 years and traveled approximately 3-3.5 hours to the nearest market. The household head's average age was 44; over half of households had completed primary education or less, with only six percent received higher education (college level or above). In terms of food security, 40 percent of the households

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were classified at being "food secure", while as much as a quarter were considered being "food insecure with hunger".[1] In terms of the village's social composition, over 90 percent of households were male-headed, with a majority of them (approx. 80 percent) working age (defined as being less than 65 years old at the time of survey). Approximately 70 percent of households self-reported their paternal ethnicity as belonging to the major ethnic group in their settlement. Between 25-35 percent households either rely primarily or partially on fishing as a way to meet their needs. Thirty percent of the population stated that they possessed the rights to manage, exclude, or transfer marine resources. There is a high level of community involvement in our settings; approximately two-thirds of the population participated in at least one community group (either focused on marine resource management, religious activities, or other community actions) during the year prior to the survey.

Validity assumption of the Difference-in-difference method

An important prerequisite to estimating MPA causal effects is to check for the validity of the underlying DiD assumption, that treatment and control groups were identical and following a parallel economic well-being trend at baseline. This prerequisite ensures that households in control settlements serve as appropriate counterfactuals to the treated households since they were not exposed to the policy intervention. As discussed, the survey design's coarse settlement-level matching approach ("coarse matching") specifically identified and selected comparable control settlements in each MPA cluster to conduct household interviews. This matching procedure relied on secondary data covering four pre-treatment sociodemographic criteria: distance to market, predominant livelihood, political jurisdiction, and ethnic composition. In addition, the process incorporated expert judgment through focus group discussions and key informant interviews with academicians, local government officials, and NGOs operating in the area (see field manual, Glew et al., 2012, for further details).

Although the parallel-trend assumption cannot be definitively tested in our settings (we observe household indicators at only one pre-treatment period), we compare the mean values of all control and outcome variables at baseline in Supplementary Table 2. The statistics shown in the table indicate a strong baseline balance between MPA and control settlements; the means across these two groups are not statistically different from each other at any conventional confidence intervals. Notably, the non-significant difference in the subjective economic trend variable at baseline is directly supportive of the parallel-trend assumption; the data indicates that there was no significant difference in the baseline trend of subjective economic well-being before MPA establishment. Regardless, several (non-significant) differences in the magnitude of the

[1] We adopt the concept of measuring food security from (Bickel et al. 2000). Households coded as being "food secure" are those with access to safe, nutritious and socially acceptable foods. Households coded as being "food insecure with hunger" are those reported adopting one or more coping mechanisms, such as skipping meals or reducing portion size to cope with inadequate or inconsistent access to safe, nutritious and socially acceptable foods.

means exist, such as for the indicators of Time to Market and Fisher composition. To ensure that our impact estimates are robust, our subsequent analytical model controls for both of these covariates, in addition to several other household' observed characteristics (number of children, dominant ethnic composition, age of household head, and length of residency).

It is also noted that, while the coarse-matching survey design provides support to our quasi-experimental identification strategy in addressing non-random MPA placement, we cannot definitively rule out spatial spillovers in treatment given the close proximity of control sites to the MPAs. If existed, such spillovers would introduce a downward bias to our estimated causal effect. Our estimates, therefore, should be interpreted as a lower bound of the true MPA effect.

Supplementary literature review

Existing case-specific evidence with an explicit focus on understanding the disaggregated socioeconomic impacts of conservation are predominantly descriptive. Together, these studies present qualitative evidence documenting the existence of social inequality in both terrestrial and marine conservation impacts, especially focused on two dimensions, (i) gender (i.e., women or female-headed households being the more disadvantaged) and (iii) economic wealth (i.e., the poorer being more disadvantaged).

On terrestrial conservation, Hayes and Murtinho (2018) discuss the benefits and perception of fairness across wealth classes of a payment for environmental services (PES) in Ecuador; Poudel et al. (2015) and Chomba et al. (2016) discuss the unequal distribution of benefits of REDD+ programs (initiatives for reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks) across social groups in Nepal and Kenya; Bandiaky (2008) and Dawson & Martin (2015) discuss the disadvantages to under-represented groups such as female and ethnic minorities due to the lack of attention to the social complexity in designing and managing national and community-based protected areas in Rwanda and Senegal.

In marine conservation, case studies in Northern Ireland (Britton and Coulthard 2013), Tanzania (Karmat 2014), Thailand (Madeleine Gustavsson et al. 2014; Weigel et al. 2015), and Kenya (Mahajan and Daw 2016) have emphasized the gender-based wealth and employment inequality experienced by women in fishing-dependent families, female-headed households, or less socially active and inclusive communities. Social inequality has also been discussed in marine conservation through the lens of fishery livelihoods, i.e., between fishers and non-extractive marine users such as tourism workers in Greece (Oikonomou and Dikou 2008), the Philippines (Majanen 2007; Oracion et al. 2005), Bonaire island (Dixon et al. 1993), Australia (Voyer et al. 2014), and Key West, USA (Dobrzynski and Nicholson 2002). Another subgroup

focus of the marine conservation literature is based on social and economic power; studies have shown disproportional benefits of conservation initiatives to those with power and strong social ties (i.e., the elite groups or premium resource-right holders), often at the expense of indigenous groups (Bennett and Dearden 2014; Dixon et al. 1993; Mahajan and Daw 2016; Voyer et al. 2014).

Beyond qualitative studies, several theoretical analyses have introduced systematic frameworks or conceptual approaches to elicit the linkages between social equity and conservation effectiveness (Daw et al. 2011; Friedman et al. 2018; Law et al. 2018; Pascual et al. 2014; Pascual et al. 2010). Compared to the thorough descriptive evidence, there are limited quantitative studies on the magnitude and distribution of social conservation impacts that also implement an empirical design suitable for causal inference (Gill et al. 2019).[2] The few existing papers that meet this analytically rigorous standard predominantly investigate heterogenous effects of terrestrial protected areas (e.g., Clements et al. 2014; Ferraro and Hanauer 2011; Keane et al. 2019).

Within the literature on marine protected areas, quantitative evidence, with an explicit focus on how the magnitude of marine conservation effects vary within and among social groups, has been called for in order to better inform equitable policy making (Mascia et al. 2017; Mascia et al. 2010), but is currently still lacking. According to the author's knowledge, Gurney et al. (2015) is the only existing quantitative study that employs a counterfactual design to evaluate the distributional impacts of marine protected areas across major social subgroups (gender, age, religion). Analyzing a long-term household survey dataset covering over 2,000 households in eight villages in the province of North Sulawesi, Indonesia (four treatment and four control villages), the study finds limited evidence that socioeconomic impacts varied across groups. Relative to Gurney et al. (2015), our analysis advances the literature in several dimensions. First, we assess the impacts of ten MPAs on over 10,000 households in 180 villages, spreading across five Indonesian provinces. These MPAs encompass a broader heterogeneous set of ethnic, religious, livelihood, and social-practicing compositions of households and individuals, thus offering extensive social subgroup variations. Second, we focally integrate a dual subjective-objective economic well-being analysis, thereby emphasizing the importance of gaining a multi-faceted understanding of MPA differential effects across

[2] McKinnon et al. (2016) performs a review that covers 1,043 existing studies of nature-conservation impacts on human well-being and concluded that robust and quantitative evidence is limited: only 9% of total existing papers applied some forms of quantitative method to examine causal effects of interventions, among which only 67 existing papers followed rigorous impact-evaluation approaches (i.e., considered a counterfactual by which to compare and attribute effects of interventions). The limited existing quantitative studies also focus on the heterogeneities by gender (Gurney et al. 2015 and Maharjan et al. 2009); wealth (Jagger et al. 2018; Maharjan et al. 2009; McNally, Uchida, and Gold 2011; Sommerville et al. 2010); and fishery dependence for the case of MPAs (McNally, Uchida, and Gold 2011; Svensson, Rodwell, and Attrill 2010; Vogt 1997).

domains of well-being (Gill et al. 2019; Rasheed 2020). Third, in addition to measuring the distributional impacts, we explore potential factors that influence how impacts are distributed across sub-groups, giving quantitative insight on important moderators of conservation impacts (Ferraro and Hanauer 2015).

II. SUPPLEMENTARY TABLES

Supplementary Table 1: Characteristics and number of settlement and surveyed households within each MPA study site in the Bird's Head ([A]) and Sunda Banda ([B]) Seascapes

MPA Name	Abbreviated MPA Name	MPA Population (2010)	MPA Size (km^2)	Sampled MPA Settlements (total MPA Settlements sampled incl. non-MPA)	Number of Surveyed Households					
					MPA			Control		
					Base line	1st Post line	2nd Post line	Base line	1st Post line	2nd Post line
Teluk Mayalibit [A]	Mayalibit	3,000	3,660	11 (14)	260	270	243	94	112	66
Teluk Cenderawasih NP [A]	Cenderawasih	39,000	14,535	12 (23)	227	258	249	237	145	145
Kaimana [A]	Kaimana	9,200	4,998	11 (14)	211	421	384	130	102	76
Kofiau dan Pulau Boo [A]	Kofiau	3,200	1,700	4 (8)	139	140	138	132	125	124
Selat Dampier [A]	Dampier	13,000	3,360	11 (16)	308	321	313	175	176	168
Misool Selatan Timur [A]	Misool	7,700	3,660	12 (19)	234	244	243	135	144	144
Selat Pantar [B]	Selat Pantar	196,613	2,767	19 (26)	273	259	-	130	104	-
Flores Timur [B]	Flores Timur	241,082	1,500	21 (28)	284	259	-	130	129	-
Kei Kecil [B]	Kei Kecil	58,000	1,500	14 (19)	248	269	-	146	146	-
Seram Bagian Timur MPA [B]	Koon	500	99	9 (13)	214	243	-	126	130	-

Supplementary Table 2: Descriptive statistics of main variables (baseline data)

	MPA Settlements			Control Settlements		
Indicators	**N**	**Mean**	**S.D.**	**N**	**Mean**	**S.D.**
Panel A: Economic wellbeing (main outcome indicators)						
Poverty exposure index (Asset-based; objective)	2380	0.475	0.336	1422	0.483	0.334
Economic trend: stable/improved (%) (Perception; subjective)	2387	0.793	0.405	1430	0.747	0.435
Panel B: Covariates in causal inference model						
Time to market (hours)	2398	2.905	3.974	1435	3.548	4.053
Number of children	2398	2.495	1.926	1435	2.516	1.956
Dominant ethnicity (composition; %)	2398	0.721	0.448	1435	0.706	0.456
Age of household head (years)	2370	44.084	12.603	1396	44.965	12.462
Residency (years)	2374	32.021	18.755	1422	32.134	18.419
Panel C: Benchmark indicators						
Education of household head						
None or primary school	2398	0.523	0.500	1435	0.506	0.500
Junior secondary school	2398	0.246	0.431	1435	0.245	0.430
Senior secondary school	2398	0.172	0.378	1435	0.189	0.392
Higher or further education	2398	0.059	0.236	1435	0.060	0.237

Food Security						
Food secure (%)	2390	0.387	0.487	1427	0.359	0.480
Food insecure without hunger (%)	2390	0.339	0.474	1427	0.381	0.486
Food insecure with hunger (%)	2390	0.274	0.446	1427	0.260	0.439
Panel D: Subgroup composition (household head; binary for each category)						
Male (%)	2398	0.936	0.244	1435	0.909	0.287
Fisher (occupation; %)	2393	0.347	0.476	1432	0.249	0.433
Working age (below 65; %)	2370	0.790	0.407	1396	0.778	0.416
Adat (have premium tenure rights; %)	2381	0.301	0.459	1408	0.319	0.466
Panel E: Moderating indicator						
Community participation (%)	2398	0.620	0.485	1435	0.697	0.460

Supplementary Table 3: Household asset items & cooking fuel material in PCA poverty index construction

Asset-ownership Indicator (lack thereof)	Poverty Exposure PCA Weight (%)
Household does not have…	
TV	34.230
Other Entertaining Assets	22.651
Satellite Dish	21.899
Generator	10.965
Phone	5.548
Boat	1.595
Motorcycle	1.541
Bicycle	0.826
Car/Truck	0.006
Household uses non-biomass cooking fuel	0.738

Note: This table shows the list of the underlying household's asset items and their corresponding weights in the construction of the PCA poverty alleviation index. Entertaining assets include ownerships of at least a Radio/Stereo/CD player/ DVD player; phone assets include ownerships of at least a mobile or a landline telephone; boat assets include ownerships of at least a boat without motor/with outboard motor/with inboard motor; non-biomass cooking fuel is defined as the use of electricity or oil for cooking purposes (as opposed to wood/charcoal/scrap wood/weeds, leaves, dung as burning materials). The weights sum to 100.

Supplementary Table 4: MPA impacts on poverty alleviation, perceived economic stability or improvement, and inequality in poverty alleviation (settlement-level)

	(1)	(2)	(3)	(4)
[Panel A] Dependent variable: Poverty Alleviation Index				
Post	0.039*	0.021	0.041*	0.025
	(0.022)	(0.045)	(0.022)	(0.047)
MPA X Post	-0.037	-0.032	-0.031	-0.023
	(0.026)	(0.026)	(0.027)	(0.027)
Observations	457	457	406	406
Adjusted R^2	0.17	0.182	0.2	0.209
[Panel B] Dependent variable: Perceived Economic Stability and Improvement (%)				
Post	0.061***	0.087**	0.063***	0.120***
	(0.022)	(0.043)	(0.024)	(0.046)
MPA X Post	-0.009	-0.014	-0.015	-0.029
	(0.026)	(0.025)	(0.028)	(0.026)
Observations	477	477	423	423
Adjusted R^2	0.085	0.213	0.076	0.22
[Panel C] Dependent variable: GINI of Poverty Alleviation Index				
Post	-0.038*	-0.017	-0.041*	-0.023
	(0.021)	(0.043)	(0.021)	(0.045)
MPA X Post	0.028	0.027	0.025	0.023
	(0.024)	(0.025)	(0.025)	(0.026)
Observations	457	457	406	406
Adjusted R^2	0.107	0.101	0.133	0.122
MPA-cluster Fixed Effects	Yes	Yes	Yes	Yes
Interview Year Fixed Effects	No	Yes	No	Yes
Settlement Covariates	No	No	Yes	Yes

** p<0.1, ** p<0.5, *** p<0.01.*

Note: This table presents the settlement-level difference-in-difference (DiD) regression results for poverty alleviation index (panel A), likelihood that household indicated a positive perception of economic condition (panel B), and the Gini index of poverty alleviation (panel C). Gini scores were calculated for each settlement-year. Regressions for poverty alleviation and Gini index excluded settlements where households provided non-complete information on their ownership of asset items used for the asset-based poverty index construction. Settlement covariates in columns 3-4 includes average travel time to nearest market, baseline fishery household composition, baseline customary governance likelihood, and settlement's geographic location (latitude and longitude).
DiD regressions utilize linear Ordinary Least Square (OLS) estimation with fixed effects. Robust standard errors are clustered at the settlement level and shown in parentheses. Stars represent the level of statistical significance: * p<0.1, ** p<0.5, *** p<0.01. Refer to Equation (2) for a complete discussion of the econometric model.

Supplementary Table 5: Subgroup impacts: DiD regression results

	Female	Male	Retired	Working	Adat	non-Adat	Fisher	non-Fisher
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
[Panel A] Dependent variable: Poverty Alleviation Index								
Post	0.097	0.001	0.042	-0.001	-0.037	0.039	-0.022	0.016
	(0.088)	(0.023)	(0.052)	(0.027)	(0.041)	(0.034)	(0.055)	(0.029)
Treatment X Post	-0.036	-0.014	-0.041	-0.014	0.004	-0.016	0.021	0.031*
	(0.057)	(0.016)	(0.036)	(0.017)	(0.030)	(0.020)	(0.029)	(0.018)
Observations	765	8,812	2,158	7,263	2,518	6,843	2,571	7,006
R^2	0.312	0.147	0.240	0.154	0.196	0.160	0.165	0.174
Adjusted R^2	0.104	0.127	0.159	0.128	0.135	0.134	0.101	0.148
Residual Std. Error	0.311	0.312	0.313	0.311	0.307	0.314	0.314	0.312
[Panel B] Dependent variable: Perceived Economic Stability or Improvement (%)								
Post	0.213*	0.126***	0.196***	0.116***	0.212***	0.094**	0.120*	0.141***
	(0.114)	(0.036)	(0.066)	(0.038)	(0.052)	(0.039)	(0.063)	(0.043)
Treatment X Post	-0.147**	-0.025	-0.052	-0.039	-0.054	-0.039	-0.002	-0.054**
	(0.068)	(0.022)	(0.043)	(0.024)	(0.044)	(0.024)	(0.036)	(0.027)
Observations	804	9,232	2,327	7,557	2,537	7,064	2,623	7,413
R^2	0.294	0.069	0.141	0.071	0.130	0.076	0.109	0.070
Adjusted R^2	0.088	0.047	0.056	0.044	0.060	0.047	0.040	0.042
Residual Std. Error	0.380	0.380	0.389	0.378	0.389	0.377	0.377	0.383
MPA-cluster FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Interview Year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: This table provides the difference-in-difference (DiD) regression results corresponding to Figure 3. Each column shows outputs from a separate subgroup regression. The dependent variable is household's poverty alleviation index in Panel A, and the likelihood that household indicated a positive perception of economic condition (Panel B). The estimated coefficients *Treat X Post* and *Post* correspond with α_1 and α_2 in the DiD Equation (1), respectively. Due to space constraint, estimated coefficients for household covariates are not shown but available upon request. DiD regressions utilize linear Ordinary Least Square (OLS) estimation with fixed effects. Robust standard errors are clustered at the settlement level and shown in parentheses. Stars represent the level of statistical significance: * p<0.1, ** p<0.5, *** p<0.01. Refer to Equation (2) for a complete discussion of the econometric model.

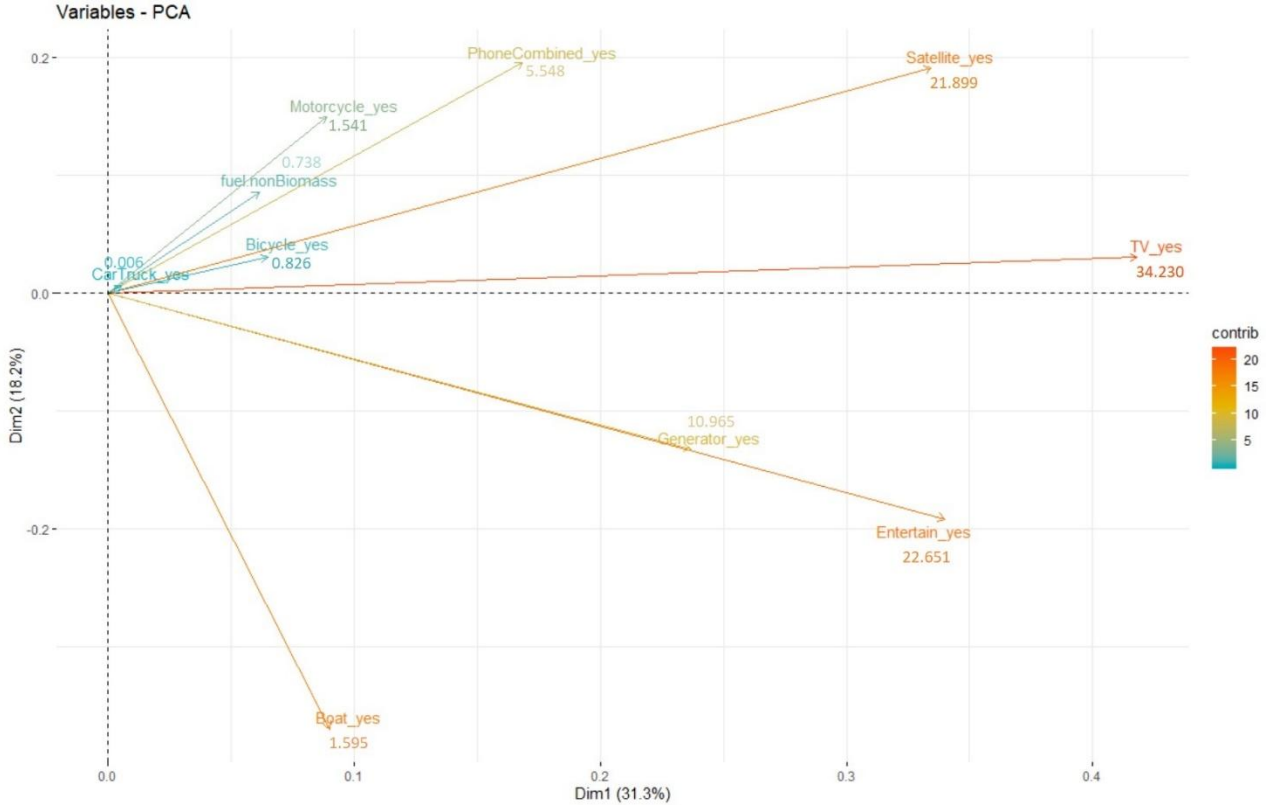
Supplementary Table 6: Summary statistics of community participation by subgroups (baseline)

Subgroup Participation (%)	N (settlements)	Mean	SD	Median	Min	Max
Gender:						
Female	180	0.386	0.446	0.000	0	1
Male	180	0.635	0.287	0.667	0	1
Age Groups:						
Retired	180	0.552	0.381	0.500	0	1
Working	180	0.640	0.296	0.707	0	1
Fishery Livelihoods:						
Fisher	180	0.536	0.394	0.578	0	1
non-Fisher	180	0.616	0.306	0.628	0	1
Tenureship:						
Adat	180	0.624	0.404	0.771	0	1
non-Adat	180	0.587	0.316	0.600	0	1
Overall	180	0.632	0.281	0.650	0	1

Note: This table provides the summary statistics of community participation by subgroups, using the baseline year for each settlement observation. The participation indicator takes value of 1 (high participation; above-MPA-median) and 0 (low participation; below-MPA-median). The mean statistics reflects the share of settlements in the analysis sample in which the average number of community organizations of each of the listed subgroups is higher than the MPA median number.

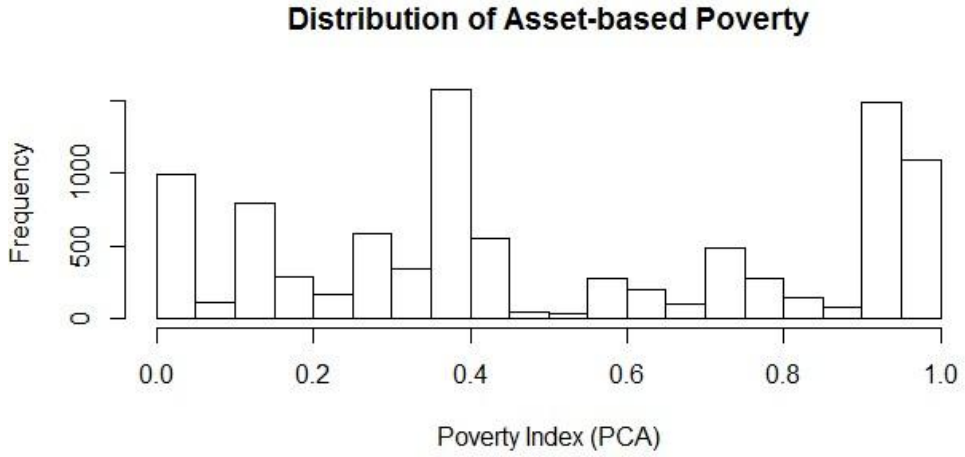
III. SUPPLEMENTARY FIGURES

Supplementary Figure 1: Poverty alleviation index's asset components (PCA)



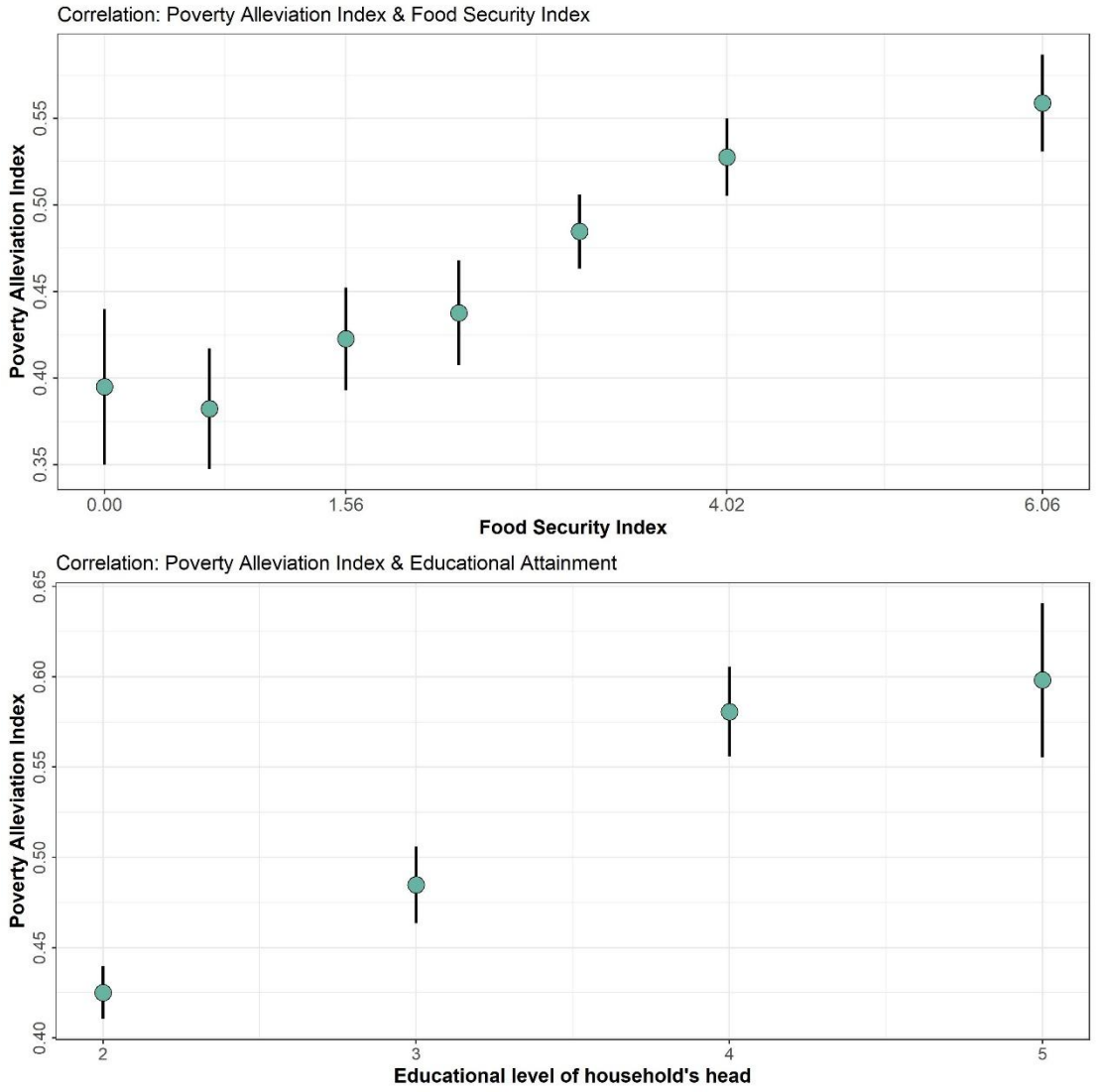
Note: This figure shows the underlying components (binary indicators of asset ownership) of the constructed household-level PCA poverty alleviation index. The poverty alleviation index was obtained from retaining the first principal component (Dimension 1 on the plot), that which captures the most variance among the combination of asset ownership and cooking fuel usage factors. The relative x-component's magnitude and angle (relative to horizontal axis) of each arrow vector reflects explanatory relationship (variance contribution) between the corresponding individual asset-ownership indicator and the principal component, i.e., representing the weight toward the index calculation.

Supplementary Figure 2: Distribution of the Asset-based poverty alleviation index



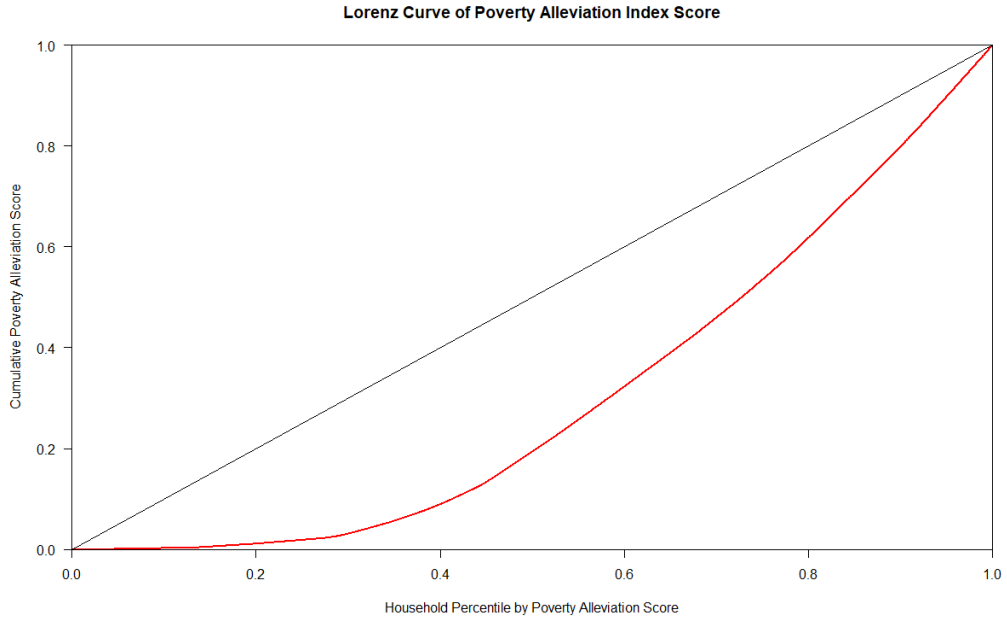
Note: This figure shows the histogram of household-level poverty alleviation index (PCA) distribution in our sample. By design, the value of the index ranges from 0 to 1. At the polar, an index score of 1 indicates no existence of poverty: household possesses at least one of each of the nine asset components and uses non-biomass materials as cooking fuel. In contrast, an index score of 0 indicates absolute poverty: the household owns none of any of the asset component and cooks with biomass fuel. Thus, a greater index score represents greater poverty alleviation (or less poverty exposure).

Supplementary Figure 3: Correlations of poverty alleviation index and food security/educational attainment



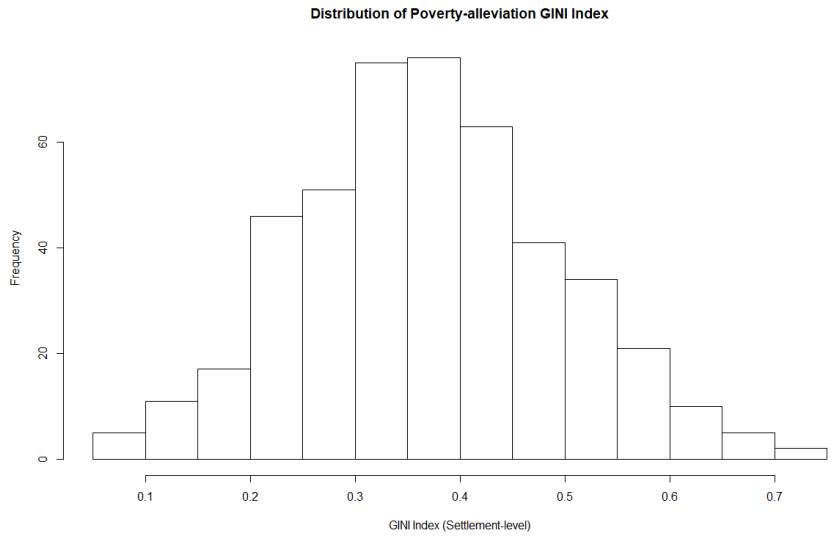
Note: This figure shows the correlation between the asset-based poverty alleviation index and two alternative economic benchmark indicators: 1. household's food security level (upper panel) and 2. household head's educational attainment (lower panel). Underlying data and the construction of these two benchmark indicators are discussed in the Methods section. Green dots represent mean index score of poverty exposure at each food security and educational level threshold. Whiskers represents 95% confidence interval.

Supplementary Figure 4: Inequality in poverty exposure: Lorenz curve



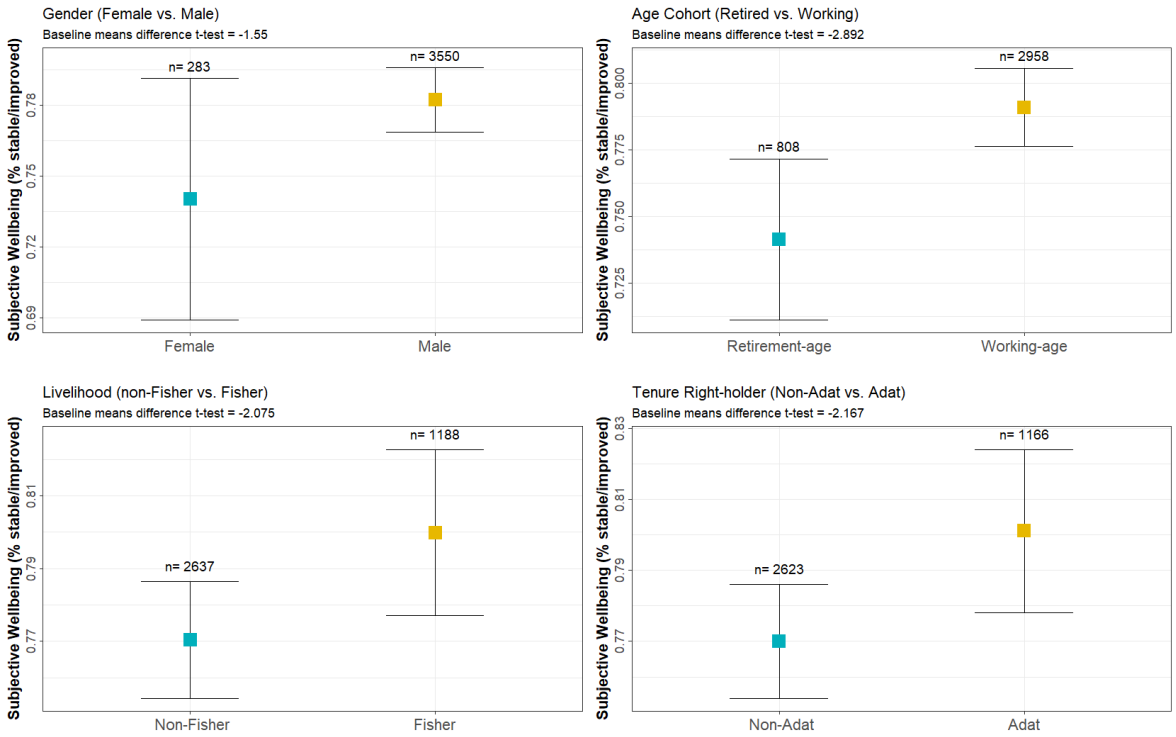
Note: This figure plots the Lorenz curve (in red) as a graphical representation of baseline inequality in household's asset-based poverty alleviation exposure. Horizontal axis represents the percentile distribution of households based on the index score. Vertical axis represents the cumulative poverty alleviation score. For benchmarking purpose, straight diagonal line (slope=1) represents perfect equality in poverty distribution ("equality line"). The magnitude of deviation of the Lorenz curve from equality line illustrates the level of inequality in households' poverty alleviation measure.

Supplementary Figure 5: Distribution of settlement-level poverty-alleviation GINI index



Note: This figure shows the histogram distribution of settlement-level GINI scores of the household's poverty alleviation index. GINI scores were calculated for each settlement-survey round. A greater GINI indicates higher level of inequality in the distribution of household's poverty exposure.

Supplementary Figure 6: Baseline subjective economic wellbeing across subgroups



Note: Subjective economic wellbeing across subgroups; baseline condition (measured as the likelihood of individual perceiving a stable and improved economic condition during the survey period before MPA implementation). Subgroups are 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 great likelihood indicates greater perceived improvement.