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LETTER

The long-term impacts of Marine Protected Areas on fish catch and socioeconomic development in Tanzania

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Abstract
Marine Protected Areas (MPAs) are a cornerstone of marine conservation efforts, with the potential to protect biodiversity and provide socioeconomic benefits. We quantified the effect of MPAs on fishing outcomes, economic activities, and material living standards in 24 coastal villages of Tanzania over two decades. We accessed original data from a study conducted in 2003 that found no effect of MPAs 3–8 years after their creation. Eighteen years later, we replicated the survey and used a Before-After Control-Intervention design to quantify the effect of MPAs. We found that villages near MPAs experienced a 50% higher improvement in living standards compared to those further from MPAs. This benefit is not related to higher fishing outcomes but to a diversification of economic sectors. Our findings highlight a decoupling between fish catches and economic benefits, revealing that socio-economic outcomes can be observed for MPAs whose ecosystems' productivity has declined.

KEYWORDS
biodiversity, conservation social science, coral reefs socioecosystems, impact evaluation, Marine Protected Areas, Tanzania, Western Indian Ocean

1 | INTRODUCTION

The global collapse of marine biodiversity (O'Hara et al., 2021; Pacoureau et al., 2021) is altering the functioning and resilience of the oceans with direct consequences on the contributions nature provides to human populations (Eddy et al., September, 2021). In the search for sustainable policies benefiting people and nature, multiuse Marine Protected Areas (MPAs) are increasingly promoted (Gill et al., 2024). They permit various economic activities within protected seascapes, including fishing, while offering stronger regulations than outside MPAs regarding fishing periods, areas, and gear (Grorud-Colvert et al., 2021). However, the effect of multiuse MPAs on ecosystems, fish biomass, and socioeconomic outcomes remains uncertain, debated, and understudied, particularly in the long-term (Ban et al., 2019; Cinner et al., 2019; Gurney et al., 2014; Mascia et al., 2010; Pécastaing & Salavarriga, 2022; Turnbull et al., 2021).

Our study quantifies the effect of multiuse MPAs on fish catches, sources of livelihoods and material living standards over two decades in Tanzania, hence providing one of the longest longitudinal studies published on this topic. Coastal ecosystems in the Western Indian Ocean, including Tanzania, are under great pressure from overexploitation and climate change (Andrello et al., 2022). On the economic side, Tanzania has experienced one of the world's fastest decreases in extreme poverty since the early 2000s (World Bank, 2022). While fisheries support the livelihoods of 4.2 million people (Peart et al., 2021), catches have collapsed since the 1980s because of overfishing by both local and international fishing fleets (Silas et al., 2020). Marine conservation initiatives started in the 1970s (Machumu & Yakupitiyage, 2013; World Bank, 2021). Tanzania's first marine national park, Mafia Island Marine Park (MIMP), was created in 1995 (Horrill et al., 1996). The mid-1990s saw the creation of several MPAs composed of a small no-take zones surrounded by large multiuse areas. These initiatives include MPAs that are legally designated with sworn officers among their staff (State MPAs), and local conservation initiatives, often facilitated by NGOs, that are based on community involvement, with locally approved management plans, not necessarily codified into the law (local MPAs) [(Ngoile & Linden, 1997) and table 1 in Tobey and Torell (2006)]. All of the MPAs implement complementary socioeconomic activities alongside conservation actions (e.g., apiculture, agriculture, aquaculture) (Tobey & Torell, 2006).

In 2003, 3–8 years after the creation of these multiuse MPAs, Tobey and Torell (2006) showed that living standards in villages located near or inside MPAs (referred to villages "with" an MPA hereafter) were mostly not different from those located further from ("without") MPAs. Since 2003, marine conservation efforts have expanded: villages initially without an MPA experienced the creation of an MPA, and villages initially under only local protection are now within the perimeter of State-managed MPAs.

Eighteen years after this original study, we replicated the protocol in the same villages with new respondents to study the long-term socioeconomic effects of MPAs using a Before-After-Control-Impact (BACI) model. Our study complements the existing literature by analyzing significantly longer effects than those usually documented, and by using a methodology that allows the identification of causal impacts (Ban et al., 2019; Wauchope et al., 2021).

2 | METHODS

We collected data in 24 villages located in six main regions: Tanga, Pemba Island, Unguja Island, Mafia Island, and Kilwa (Figure 1). Fisheries are oriented toward emperor fish (Family: Lethrinidae), painted sweetlips (Haemulidae), rabbitfish (Siganidae), and sardines (Dorosomatidae).

All MPAs included in this study are zoned multiple use area. Regulated fishing activities are authorized within large general-use and specified-use zones. Fishing activities are, *de jure*, forbidden within smaller no-take core zones. Core zones represent, for example, 0.05% of Pemba Channel Conservation Area and 1% of Tanga Coelacanth Marine Park according to their most recent management plans.

We detailed decisions related to sampling, outcomes, and hypothesis testing in a preanalysis plan (RIDIE-STUDY ID 61d2b5b8150cf: link and Supporting Information 1). We report main deviations from this plan in Supporting Information 2.

2.1 | Data

We obtained original data from the 2003 surveys from Tobey and Torell (2006). These surveys were conducted in May and June 2003 with 749 heads of households (86% male). We replicated their design in 2021. We used the Google Open Building database v1 (Sirko et al., 2021) to randomly sample 35 new households in each village. We added outcomes relative to the enforcement of MPAs that were not measured in 2003. We collected data between September 2021 and January 2022 ($n = 808$). Our analyses considered wind speed data from ERA-5 (Hersbach et al., 2020), as wind speed could affect oceanic conditions and prevent fishers from setting sail to fish. We provide additional details on data collection in Supporting Information 3. Table 1 presents summary statistics for the main outcomes and socioeconomic characteristics.

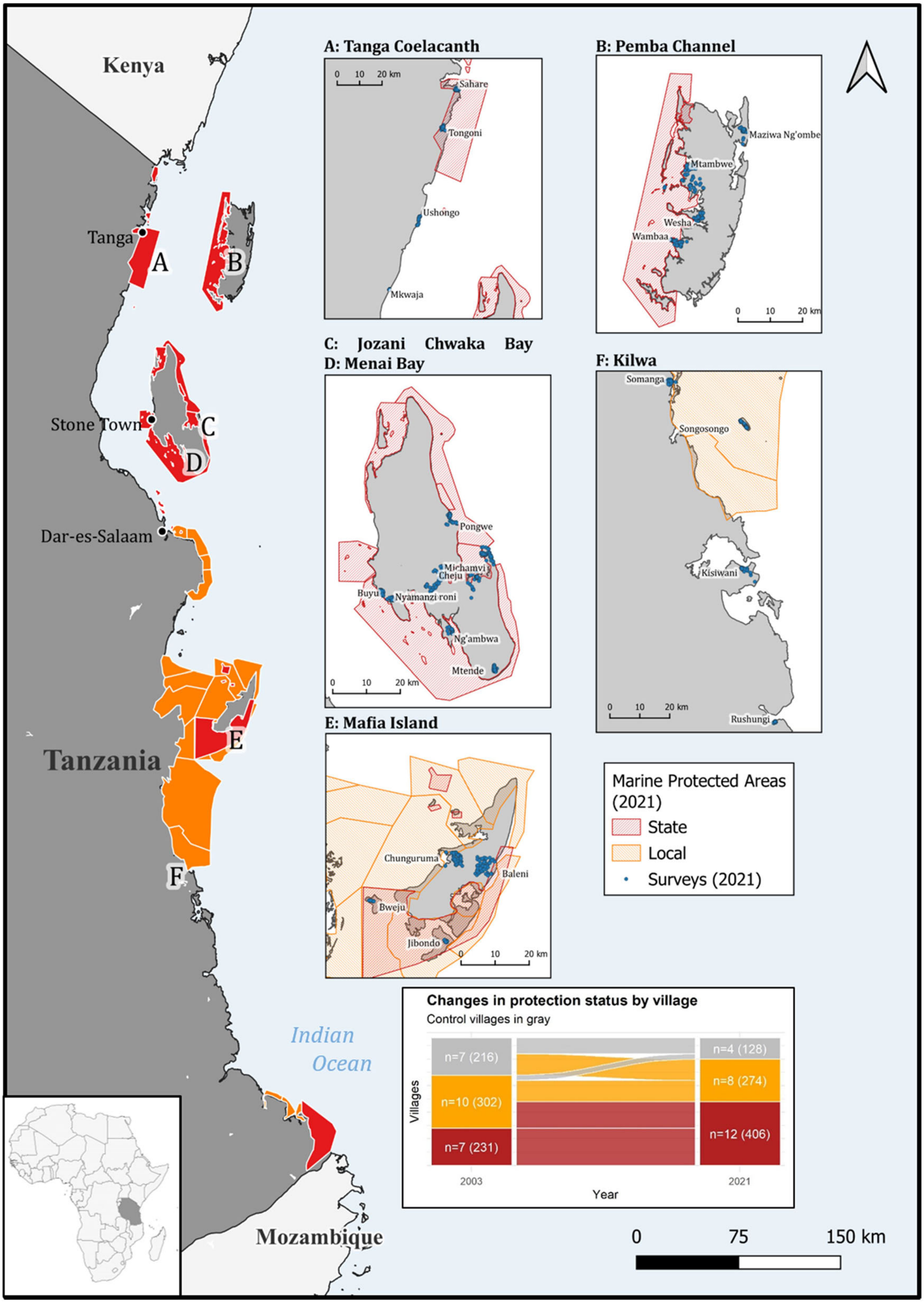

FIGURE 1 General study area. Insets A–F provide details of Tanzanian MPAs as of 2021, surveyed villages, and household survey respondents (blue). The alluvial diagram (bottom) illustrates changes in villages' protection status between 2003 and 2021.

TABLE 1 Descriptive statistics.

		2003 (*N* = 749)		2021 (*N* = 808)			
		Mean	**SD**	**Mean**	**SD**	**Diff. in means**	**SD**
Gender (1 if female)		0.1	0.3	0.4	0.5	0.3	0.02
Age (years)		44.1	14.4	44.3	14.9	0.2	0.7
Fishing days last 30 days		7.6	9.5	7.8	9.0	0.2	0.5
Wind speed (m/s)		27.0	8.4	18.2	4.7	−8.8	0.3
Primary education (1 if finished)		0.8	0.4	0.9	0.3	0.05	0.02
Household head (1 if yes)		1.0	0.1	0.7	0.5	−0.3	0.02
Fished in last 7 days (1 if yes)		0.3	0.5	0.4	0.5	0.03	0.02
Fished in last 30 days (1 if yes)		0.4	0.5	0.6	0.5	0.1	0.03
Catch per unit of effort 30 days (kg)		21.6	26.5	10.9	21.2	−10.7	1.8
Living standard index		2.4	1.6	6.0	3.0	3.6	0.1
Agriculture/livestock last 7 days (1 if yes)		0.4	0.5	0.2	0.4	−0.1	0.02
(Self-)employed last 7 days (1 if yes)		0.2	0.4	0.2	0.4	0.08	0.02
Not working last 7 days (1 if yes)		0.04	0.2	0.08	0.3	0.05	0.01
		N	Pct.	*N*	Pct.		
Region	Kilwa	122	16.3	128	15.8		
	Mafia	132	17.6	128	15.8		
	Pemba	120	16.0	129	16.0		
	Tanga	121	16.2	129	16.0		
	Unguja	254	33.9	294	36.4		
MPA (all)	Without	216	28.8	128	15.8		
	With	533	71.2	680	84.2		
State MPA	Without	216	28.8	128	15.8		
	With	231	30.8	406	50.2		
Local MPA	Without	216	28.8	128	15.8		
	With	302	40.3	274	33.9		

Note: This table summarizes descriptive statistics for all the main outcomes included in our analysis. *N* refers to the number of observations, SD to the standard deviation and Pct to the percentage of observations. For each continuous variable, we present the mean and standard deviation for 2003 and 2021, along with the difference in mean between the 2 years. For categorical variables, we present the number of observations and percentage.

2.2 | Primary outcomes

Our study primarily focuses on fish catches, fishing intensity, sectoral activities, and living standards. We measured fish catches through a recall question over the last 30 days. To limit bias, respondents were able to report catches in the unit of their choices. We then converted them to kilograms and divided values by the number of days the household spent fishing over the last 30 days to obtain catches per unit of effort (CPUE). For sources of livelihood, we measured the main economic activity of household members aged 18–70 during the 7 days prior to the survey. We differentiated three sectors: (1) fishing and aquaculture, (2) agriculture and livestock, and (3) nonprimary sector activities (driving, selling crafts or food, tourism etc.).

Lastly, we assessed material living standards using a multidimensional index (Alkire et al., 2015) synthesizing 15 covariates, covering the household's dwelling (ownership and quality), access to water, sanitation, electricity, ownership of durable goods (phone, motorbike), and of a bank account. Each item was given the same weight and summed. Our index is similar to the "wealth index" developed by the Demographic and Health Surveys (DHS) program and is widely used in the social sciences.

2.3 | Marine Protected Area treatment

We constructed a dummy variable that equals one if an MPA was present in or nearby village j during year t, and zero otherwise. We followed Tobey and Torell (2006) to identify whether a village had an MPA in 2003 and the WIOMSA Outlook (World Bank, 2021) to classify protection status in 2021.

In 2003, 17 villages were located nearby MPAs [Tanga Coastal Zone Conservation and Development Program (TCZCDP), MIMP, Menai Bay Conservation Area, Jozani-Chwaka Bay Conservation Area, Misali Island Conservation Area]. Seven villages, located further away from MPAs, were selected as "control" villages in consultation with local and national officials and MPA project staff (Tobey and Torell, 2006). Between 2003 and 2021, part of TCZCDP was transformed into the Tanga Coelacanth Marine Park, and conservation activities were spatially extended around Unguja and Pemba. In 2021, households from 20 villages lived within 5 km from the boundary of an MPA. We classify them as "treated" observations in the analysis [mean distance to the nearest MPA = 0.8 km, standard deviation (SD) = 1 km]. Households from the other four villages lived 10 to 70 km away from MPAs and were classified as "control" observations.

2.4 | The effect of MPAs on socioeconomic outcomes

We pooled surveys from 2003 and 2021, and for each outcome, we estimated a model of the form:

$$\begin{aligned} Y_{i,j,r,t} &= \beta_0 + \beta_1 MPA_{j,t} + \beta_2 \lambda_t + \beta_3 MPA_{j,t} \times \lambda_t + \gamma X_{i,t} \\ &+ \mu \nu_{j,t} + \theta_r + \varepsilon_{i,j,t}, \end{aligned}$$

where $Y_{i,j,r,t}$ are outcomes for an individual i, living in village j, located in region r (Kilwa, Mafia, Pemba, Tanga, Unguja), during year t. $MPA_{j,t}$ is a dummy variable indicating whether an MPA is located near village j during year t (Control-Intervention dummy). λ_t is a dummy variable for the year. It controls for common time-varying unobserved characteristics (Before-After dummy). $MPA_{j,t} \times \lambda_t$ is an interaction term set to 1 in villages with an MPA after their creation, and set to 0 before their creation and in control villages. $X_{i,t}$ is a set of individual socioeconomic characteristics (age, gender, whether the respondent finished primary school, situation with respect to the head of household). $\nu_{j,t}$ is the wind speed in village j during the month of the survey in year t. θ_r is a dummy variable to control for time-invariant unobserved characteristics at the regional level.

In the regressions, we standardized continuous outcomes based on the average value of the variable in the control group in 2003. Effects can then be interpreted as standard deviations of the outcomes and compared between each other. For continuous outcomes (CPUE, number of fishing days, asset index), we estimated the model parameters using ordinary least squares. For binary outcomes (whether the respondent fished in the past seven or 30 days, whether he/she practiced a given employment / activity in the past 7 days), we used logistic models (generalized linear model with a logit link function) and reported coefficients of the mean marginal effect. For all models, we assumed heteroskedastic error terms (HC3). We provide results with clustered standard errors in Supporting Information 5.2.

State and local MPAs can differ in terms of their protection status, financial and technical capacities, and regarding the activities they implement. This can have direct consequences on their impact (McClanahan et al., 2006; Zhang et al., 2023). In order to test for a possible heterogeneous impact, we further conduct subsample analyses in which we compare (1) local MPAs with control villages to measure the effect of local MPAs and (2) State MPAs with control villages to measure the effect of State MPAs.

The identification of a causal effect of MPAs relies on the change of protection status in villages, once observed individual characteristics, regional unobserved characteristics and common unobserved time characteristics have been accounted for. Our specification departs from a standard BACI because some villages already had an MPA in 2003 (Wauchope et al., 2021). We relax this hypothesis in Supporting Information 5.3.

2.5 | Perception of the impact by the villagers and experts

During the 2021 household survey, we added questions related to the perception of the impact of MPAs. These questions are asked only to respondents in control and treated villages who reported knowing MPAs.

We also ran an online survey with local and international experts of MPAs and asked them to predict the expected outcomes of our study. We received 14 responses. Half of them were academics (n = 7). The other half worked for governments (n = 4) and NGOs (n = 3). The experts identified themselves either as social scientists (n = 8), marine fisheries experts (n = 4), and natural scientists (n = 2).

3 | RESULTS

In 2021, respondents reported that MPAs provided some, albeit limited restrictions: 74% of respondents knew about the existence of MPAs (76% in villages with an MPA, 65% in villages without MPA, $p = 0.02$). Only 49% of households acknowledged the existence of some level of enforcement to protect fish stocks and marine wildlife (53% in villages with an MPA, 29% without an MPA, $p < 0.001$). However, only 10% of the respondents in villages with MPAs

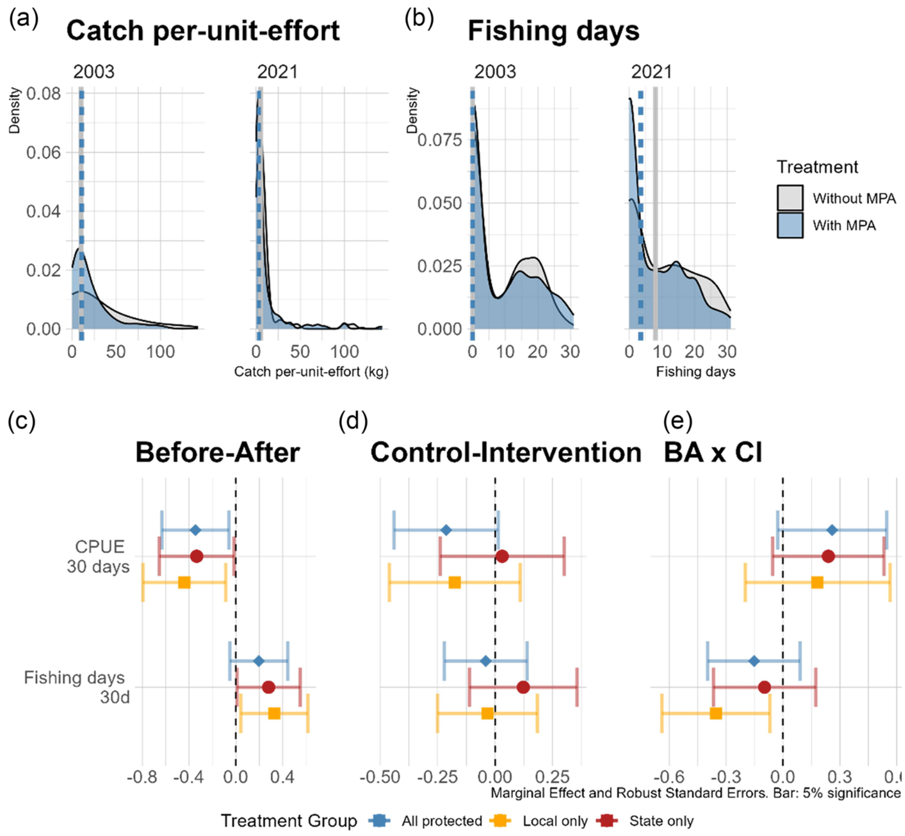

FIGURE 2 A and B: Distribution of catches per unit of effort and the number of fishing days (recall period = last 30 days) in 2003 (left) and 2021 (right) for villages with (blue) and without (gray) MPAs. Vertical lines represent the median for each year and treatment status. C: Before-After (BA) coefficient of our main regression. D: Control-Intervention (CI) coefficient of our main regression. E: Coefficient of the interaction term between BA and CI. All coefficients are expressed in terms of standard deviation for comparability. The BA × CI coefficient best represents the causal impact of MPA. In C, D and E, we present results for all MPAs combined (blue) and for subsamples showing locally managed (red) and State-managed (orange) MPAs. 95% confidence interval with heteroskedastic standard errors. Catches per level of effort (CPUE) were trimmed at the 95% level and standardized to limit measurement noise. CPUE loses significance at the 5% level once multihypothesis testing is accounted for. Main regression tables and robustness tests are reported in Supporting Information 4. Detailed results of the experts' predictions on the impact of MPAs are presented in Supporting Information 7.

considered regulations to be strong, 66% declared not having seen a park employee in the 30 past days, and 73% did not know any park employees. Table presents a breakdown of the perception of regulation by gender. The MPAs experts we surveyed also believed that MPAs enforce additional regulations imperfectly, with some variations between MPAs (Supporting Information 6).

3.1 | Fishing outcomes

Between 2003 and 2021, the estimated CPUE decreased while the number of fishing days slightly increased (Figure 2). In the BACI regression, CPUE decreased by 0.35 SD and fishing days increased by 0.3 SD (3 days per month). CPUE and fishing days were not statistically different in villages with and without MPAs. Fishers from villages where MPAs were created during the study period did not report statistically different CPUE than fishers living in villages that remained without MPAs over 18 years—suggesting that multiuse MPAs did not contribute to increasing CPUE or to decreasing fishing days. These results are true for both locally and State-managed MPAs. Out of six coefficients tested, we detected a statistically significant effect of MPA creation only on one variable: a decrease in the number of fishing days where locally managed MPAs were created (−0.35 SD, p-value = 0.015).

These results concur with experts' predictions regarding the decreasing trend in fish catches over the last two decades (9 out of 14 experts predicted a decrease; see Supporting Information 7). However, a majority of experts predicted that MPAs would increase fish catches ($n = 10$). Our findings do not support this last prediction.

Villagers' perceptions of the effect of MPA on fish catches were more aligned with our quantitative results than those of experts. Indeed, 70% of villagers believed that

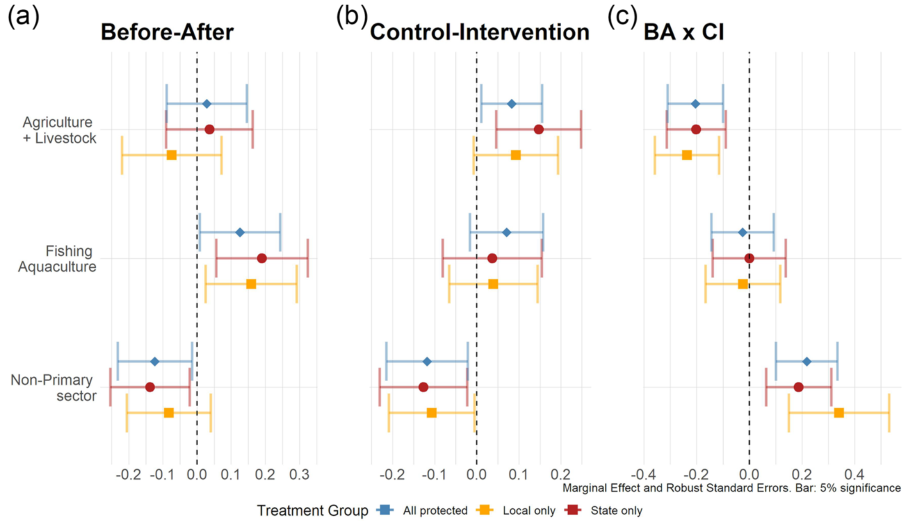

FIGURE 3 MPAs and sources of livelihoods in surveyed villages. Outcomes are binary. A generalized linear model with a logit link function was used. A: Before-After (BA) coefficient of our main regression. B: Control-Intervention (CI) coefficient of our main regression. C: Coefficient of the interaction term between BA and CI. The BA × CI coefficient best represents the causal impact of MPAs. In A, B and C, we present results for all MPAs combined (blue) and subsampled locally managed (red) and State-managed (orange) MPAs. 95% confidence interval with heteroskedastic standard errors. Coefficients represent the marginal effect at the mean of the distribution. They can be read as percentages. Results for the interaction term are statistically significant at a 5% level when correcting for multihypothesis testing (Bonferroni correction). Main regression tables and robustness tests are reported in Supporting Information 4. Detailed results of the experts' predictions on the impact of MPAs are presented in Supporting Information 7.

MPAs had no impact on fish catches and stocks (Figure S4). This perception was shared in both villages with and without MPAs.

3.2 | Sources of livelihood

Fishing was the primary economic activity in surveyed villages in 2003. Eighteen years later, the probability of a respondent having engaged in fishing activities seven or 30 days before the interview increased even further (+12% over the last 7 days, Figure 3). Fishing effort changed similarly between villages that became protected during the study period compared to villages that remained without an MPA.

Apart from fishing, MPAs have accelerated the reallocation of labor from agriculture (−20%) to self-employment and salaried off-farm jobs (+20%, Figure 3). This labor transformation was specific to villages that had become protected and did not reflect a more general trend in the economy.

In 2021, respondents were more likely to perceive a positive effect of MPAs on employment in villages nearby MPAs than in villages further away from MPAs (Figure S4). However, this positive effect was perceived only by a minority of villagers.

3.3 | Living standards

Living standards, along with inequalities, increased significantly (+2 SD, which is equivalent to 6 more items out of the 15 that compose the asset index, $p < 0.001$) between 2003 and 2021, and are structurally higher in villages with an MPA than without one (+0.5 SD, +1.5 items, $p < 0.001$, Figure 4).

The increase in living standards was faster in villages where an MPA was created between 2003 and 2021 compared to villages that remained without an MPA. The effect is economically substantial (+1.2 SD, +3 items, $p < 0.001$), meaning that living standards increased by an additional 50% in villages with an MPA compared to those without. Quantile regressions suggest that the positive effect of MPAs was experienced by poor and rich households alike (Supporting Information 4.3). In accordance with our results, a majority of surveyed experts ($n = 8$) predicted a positive impact of MPA on households' living standards. Furthermore, respondents in villages nearby MPAs were more likely to perceive a positive effect of MPAs on the general economic condition of their villages than respondents from villages without MPAs (Figure S4). Finally, 40% of respondents reported disliking certain aspects of MPAs in 2021. However, 83% of these households reported that their net opinion of MPAs was positive overall.

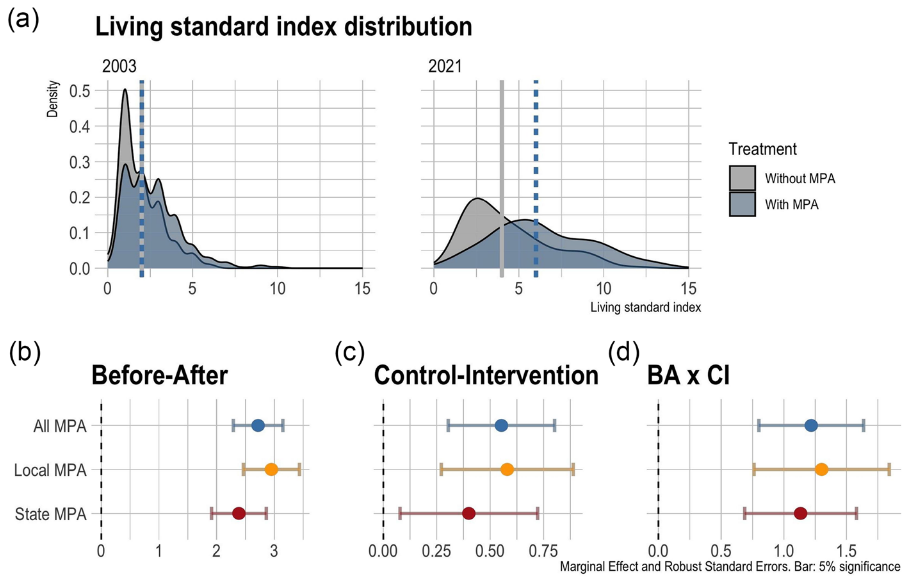

FIGURE 4 A: Distribution of asset wealth in 2003 (left) and 2021 (right) for villages with (blue) and without (gray) MPAs. Vertical lines represent the median for each year and treatment status. Values are standardized with respect to the mean and standard deviation of asset wealth in villages without MPAs in 2003. B: Before-After (BA) coefficient of our main regression. C: Control-Intervention (CI) coefficient of our main regression. D: Coefficient of the interaction term between BA and CI. The BA × CI coefficient best represents the causal impact of MPAs. In B, C, and D, we present results for all MPAs combined (blue) and subsamples restricting on locally managed (orange) and State-managed (red) MPAs. 95% confidence interval with heteroskedastic standard errors. Results for the interaction term are statistically significant at a 5% level when correcting for multihypothesis testing (Bonferroni correction). Main regression tables and robustness tests are reported in Supporting Information 4. Detailed results of the experts' predictions on the impact of MPAs are presented in Supporting Information 7.

3.4 | Robustness of findings

Supporting Information 5 provides robustness assessments for these results. In addition to preregistered tests, we show that the results are robust to restricting the sample to respondents of villages that were not treated in 2003 ($n = 444$) as in a standard BACI design. Likewise, we show that the effect on living standards is robust when dropping villages or areas from the sample, suggesting that the finding is not driven by a local specific context but reflects a more general trend (Figures S2 and S3).

4 | DISCUSSION

The impacts of multiuse MPAs on marine ecosystems and on living standards of neighboring communities remains poorly understood, partly due to a lack of robust data over long periods of time. In 2003, a study by Tobey and Torell (2006) found a limited effect of MPAs in Tanzania 3–8 years after their creation. We retrieved these data, replicated the survey, and conducted a follow-up evaluation of their impact. By using both pre- and postintervention data, we are able to establish stronger causal claims (Rife et al., 2013).

Two decades after the original evaluation, our results suggest that enforcing additional regulations in multiuse MPAs remains challenging. The difficulty of enforcing regulations within protected areas observed in Tanzanian MPAs is not specific to the local context. It reflects a more general challenge faced by conservationists across and beyond the continent (Bergseth et al., 2018; Gill et al., 2017; Lindsey et al., 2018; Smallhorn-West et al., 2022; Watson et al., 2014). As a consequence, fish catches are not more abundant following the creation of MPA in Tanzania, probably leading to limited spillovers toward fishing grounds that would be expected from effective MPAs (Smallhorn-West et al., 2022). However, we find evidence that the creation of MPAs was accompanied by a transition from farming to employment in the secondary and tertiary sectors (industry/construction and services). Furthermore, we show that the creation of multiuse MPAs was associated with a faster and economically substantial improvement in living standards. These results challenge the classical view that socioeconomic benefits from MPAs emerge from healthier and more diverse fish communities

(Nowakowski et al., 2023). This finding also highlights that it can take time for MPAs to lead to positive socioeconomic changes (Ban et al., 2019).

Since the early 2000s, Tanzania, like many developing coastal countries, has undergone important socioeconomic structural changes. Nature-based tourism has grown rapidly and delivered important economic benefits for local inhabitants in Tanzania and neighboring countries (Damania et al., 2015; Damania et al., 2019). The increase in living standards measured in our study is particularly strong in villages where tourism is a key economic sector, especially on Unguja's east coast. This suggests that tourism could be a mechanism that explains the observed faster increase in material living standards in villages close from MPAs. This would still need to be demonstrated in future studies.

MPAs can be a critical component for developing nature-based tourism, with important economic benefits for local inhabitants, both poor and rich (Damania et al., 2019). Such benefits may not be sustainable if MPAs fail to protect ecosystems and their biodiversity more effectively (Arabadzhyan et al., 2021; Kragt et al., 2009). Decreasing biodiversity could then put at risk the entire sector, with a negative multiplier effect for the entire economy. The additional cost of better protecting wildlife is likely to be negligible compared to the economic benefits of protecting ecosystems (Damania et al., 2019). Closing the financial and compliance gap that would allow MPAs to be enforced and effective is hence likely to be a sound economic decision, benefitting both people and nature (Bergseth et al., 2023).

AUTHOR CONTRIBUTIONS

RD, DM, and AL initiated the study and secured the funding. SD, JG, AL, and NJ designed the socioeconomic protocol. NJ, SD, JG, and AL supervised household surveys collection. SD, JG, and AL analyzed the socioeconomic data. SD, AL, JG, RD, DM, and LS interpreted the results. SD and RD wrote the original manuscript with inputs from DM, AL, AD, and JG. LV, LM, LS, and NJ provided comments on the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Questionnaire, data, and codes are accessible at https://zenodo.org/record/8073692

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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