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CONTRIBUTED PAPER

Effects of perceptions of forest change and intergroup competition on community-based conservation behaviors

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Article impact statement: Individuals' conservation actions in response to forest loss are contingent on secure resource boundaries and the specific action taken.

Abstract

Approximately one quarter of the earth's population directly harvests natural resources to meet their daily needs. These individuals are disproportionately required to alter their behaviors in response to increasing climatic variability and global biodiversity loss. Much of the ever-ambitious global conservation agenda relies on the voluntary uptake of conservation behaviors in such populations. Thus, it is critical to understand how such individuals perceive environmental change and use conservation practices as a tool to protect their well-being. We developed a participatory mapping activity to elicit spatially explicit perceptions of forest change and its drivers across 43 mangrove-dependent communities in Pemba, Tanzania. We administered this activity along with a questionnaire regarding conservation preferences and behaviors to 423 individuals across those 43 communities. We analyzed these data with a set of Bayesian hierarchical statistical models. Perceived cover loss in 50% of a community's mangrove area drove individuals to decrease proposed limits on fuelwood bundles from 2.74 (forest perceived as intact) to 2.37 if participants believed resultant gains in mangrove cover would not be stolen by outsiders. Conversely, individuals who believed their community mangrove forests were at high risk of theft loosened their proposed harvest limits from 1.26 to 2.75 bundles of fuelwood in response to the same perceived forest decline. High rates of intergroup competition and mangrove loss were thus driving a self-reinforcing increase in unsustainable harvesting preferences in community forests in this system. This finding demonstrates a mechanism by which increasing environmental decline may cause communities to forgo conservation practices, rather than adopt them, as is often assumed in much community-based conservation planning. However, we also found that when effective boundaries were present, individuals were willing to limit their own harvests to stem such perceived decline.

KEYWORDS
community-based conservation, conservation adoption, conservation planning, environmental change, mangroves, participatory mapping

INTRODUCTION

Problem statement

Diverse and healthy ecosystems are unequivocally humanity's best insurance against the worsening impacts of climate change (Isbell et al., 2015; Lloret et al., 2012; Loreau et al., 2001; Oliver et al., 2015). Yet, increasingly intensive resource extraction from ecosystems over the last 150 years has greatly attenuated their ability to buffer human communities against, for example, fires and flooding (Alongi, 2008; Parks et al., 2016). Simultaneously, ecosystem degradation and accompanying biodiversity loss is further accelerating climate change (Caro et al., 2022).

Recent land-use intensification strongly reflects the displacement of local communities and traditional practices by large-scale producers and outside economies (Bird et al., 2019; Ellis et al., 2021; Stephens et al., 2019). It is recognized that states and other legal structures are often insufficient to control deforestation, meaning that effective and equitable conservation efforts must empower local communities to set resource management priorities and design strategies to achieve them (Fernández-Llamazares et al., 2020; Garnett et al., 2018). Thus, achieving global conservation goals hinges, at least in part, on local community engagement and the decisions that individuals in those communities make in the environment (Gatiso et al., 2018).

Resource users can reliably detect long-term changes in their local environments (Early-Capistrán et al., 2022; Lauer & Aswani, 2010; Tengö & Belfrage, 2004). However, it is unclear how individuals' perceptions of environmental change affect their choices to limit resource use, restore ecosystems, or otherwise change their behaviors (Paloniemi et al., 2018). In particular, as pointed out by Meyfroidt (2013), few studies have linked individual perceptions of threats and change in natural resources with observed conservation behaviors and preferences (although see Nyangoko et al. [2022] and research on adaptation to climate change). A recent systematic review of 128 studies of voluntary adoption of conservation behaviors showed that although this phenomenon has been well-studied in North America and Europe (e.g., Doran et al., 2022; Grönlund et al., 2020), there is limited research on the subject in non-Western populations (Thomas-Walters et al., 2022). Hence, there is a gap in understanding of how ongoing environmental degradation is perceived by local communities and how these perceptions affect the uptake and abandonment of conservation behaviors. Delineating this relationship is critical to understanding the role of community-based conservation in achieving global conservation targets under continued environmental change.

In her foundational work, Elinor Ostrom described a set of conditions that, when met, promote cooperative behaviors in natural resource management settings (Ostrom, 1990). Among these conditions, Ostrom (1990) identifies the need to clearly demarcate and enforce proprietary access to group resources through physical and/or social boundaries. Three decades of scrutiny via case studies and meta-analyses from across the globe further cement this conclusion (Cox, 2014; Cox et al., 2010; Cumming et al., 2020). In a recent set of theoretical models, Andrews et al. (2022, 2024) delineate the social–ecological evolutionary mechanisms by which excluding outsiders promotes sustainable resource management behavior and cooperation in the face of threats to the local environment. However, the reverse is also true. These theoretical explorations demonstrate a process by which, in the absence of strong social or physical boundaries, perceived degradation of local resources may result in a race-to-the-bottom phenomenon in which individuals are incentivized to extract all they can before the resource is gone (Andrews et al., 2024).

This theory explicitly predicts that environmental degradation should promote preferences for limiting resource extraction when theft from outsiders is low. And, degradation should conversely promote preferences for increasing resource extraction when theft from outsiders is high because the gains made by sustainable management may be eroded by outsiders and never realized by the local community (Andrews et al., 2024). Experimental games played with university students similarly showed that uncertainty can encourage natural resource conservation, but this effect disappears in the presence of conflict over resources (Safarzynska, 2018). This process has, however, not been examined in the context of actual natural resource management. A real world test of these mechanisms is critical for building further theory in conservation science and for applying scientific insights on-the-ground. For example, individuals make resource management decisions under the backdrop of past exposure to external conservation interventions and within a range of acceptable community norms (Gómez-Baggethun & Ruiz-Pérez, 2011; Hayes et al., 2022). Thus, how theorized processes of behavioral change in response to environmental degradation operate in an empirical system must be observed in order to have confidence in their general importance and applicability.

We performed an empirical test of how perceived environmental degradation and threat of resource theft from outsiders affect individuals' conservation behaviors and preferences. We developed a participatory mapping activity to collect quantitative, spatially explicit perceptions of mangrove cover change in Pemba, Tanzania. We then linked these perceptions of mangrove change with a questionnaire of individual perceptions of mangrove theft and self-reports of conservation behaviors and preferences. We specifically examined individuals' self-reported frequency of patrolling behavior to protect community mangrove forests from outsiders and preferences for limits on the amount of fuelwood that community members can harvest from those forests. We quantitatively linked individuals' perception of environmental change to their conservation behaviors and intentions. We assessed these dynamics while accounting for the impact that a major conservation initiative on the island (see section below) had on individuals' conservation behaviors and preferences in the communities involved. We analyzed these empirical data with 2 distinct statistical models and interpreted the output relative to its consistency with published theoretical work on the subject. Thus, although ours is a relatively small case study, we sought to provide an empirical test of general theory regarding perceived environmental change and resource boundary efficacy on conservation behaviors and thus to increase the generalizability of the results and decrease the probability of spurious findings (Smaldino & McElreath, 2016).

METHODS

Study site

We examined community-based mangrove conservation in Pemba Island, Tanzania, the smaller of the 2 Zanzibari islands, identified as part of the Coastal Forests of Eastern Africa biodiversity hotspot. Like many low- and middle-income areas, Pemba has been subject to a series of conservation initiatives that stretch back to the colonial period. New initiatives have increased in frequency since the late 1990s. British colonial afforestation programs and the gazetting of forest reserves by the British and postrevolutionary governments began in the 1960s (Chachage, 2000). Following 50 more years of initiatives driven by a number of Scandinavian countries, in 2010 the Reduced Emissions from Deforestation and Land Degradation program (REDD+) identified 18 wards (*shehia*) in Pemba as appropriate for piloting their payments for ecosystem services conservation framework (Burgess et al., 2010; RGZ, 1996; United Nations, 1992). The REDD+ project intended to pay communities to forego harvesting fuelwood and timber and cease farm expansion inside of designated areas in each of the 18 selected shehia. The objective of this intervention was to slow deforestation, reduce greenhouse gas emissions, and reduce poverty. Although hope for this project waxed and waned over several years among Pemban communities, these payments were never delivered and the 18 selected shehia ultimately showed no measurable benefit in forest cover (Andrews et al., 2021; Collins et al., 2022).

Alongside the proliferation and succession of these conservation projects, the population on the island has grown by approximately 2.9% each year (estimate from 2012 to 2022), more than triple the global average, which has increased the need for the production of timber, fuelwood, and other forest products (URT, 2023). Approximately 90% of rural Pemban households rely exclusively on forest products (fuelwood and charcoal) to meet their daily cooking needs (Ely et al., 2000; RGZ, 2014). Further, these forest products account for 27% of total household income (Andrews & Borgerhoff Mulder, 2022). This local need for forest products contributes to a median deforestation rate of 3.4% per year in the forests of the island (Collins et al., 2022).

Although population growth is co-occurring with forest cover loss in Pemba, forest clearing and the increasingly intensive use of forest lands cannot be simply attributed to population growth (Clark et al., 2024). Indeed, some human geographers convincingly argue that there is no evidence that a smaller population size would directly decrease the rate of forest cover loss (Ojeda et al., 2020), a position for which there is some empirical support globally (e.g., Hughes et al., 2023). Histories of colonialism and exploitation greatly complicate analyses of causality (Painter & Durham, 1995), which characterizes the Zanzibari situation well, given the history of slavery and forced labor on the island (Conte, 2019) and the absence of historical data on tree cover. Regardless of the exact causal mechanisms, this decline in forest resources poses a serious problem for community well-being in Pemba.

Many individuals across Pemba recognize that forests provide valuable ecosystem services, such as erosion control. Thus, there is a conflict between the desire to safeguard local community forests and to meet daily needs. There are extensive reports that individuals adapt to this challenge by stealing forest products from the community forests of other shehia. Of communities interested in establishing community-based conservation agreements since 2010, 82% reported having trees regularly stolen by outsiders (Borgerhoff Mulder et al., 2021).

Widespread cutting of mangroves in particular has caused considerable decline of mangrove cover and resulted in flooding and saltwater intrusion in many mangrove adjacent communities (Andrews & Borgerhoff Mulder, 2022). In response, many communities and community members therein have taken it upon themselves to prohibit outsiders from stealing from their community mangroves and to reduce the harvests of their own community members. This generally takes the form of establishing village and shehia conservation committees, conducting mangrove patrols to exclude outsiders from community forests, planting mangroves, and setting specific fuelwood harvest limits. There is nevertheless considerable variability in preferences and practices of these actions on the island between and within shehia (Borgerhoff Mulder et al., 2021). We used this variability in individual preferences for limiting harvests and patrolling behavior as the outcomes of interest in this research.

Participatory mapping activity

We collected data on individual perceptions of environmental change with participatory mapping to elicit fine-scale, spatially explicit perceptions of change. Our methodology built on that of Herrmann et al. (2014) to tangibly link participant responses with specific locations and provide a more accurate measure than would be possible with a simple questionnaire (Cadag & Gaillard, 2012; Emmel, 2008). The intention was not to document actual changes in forest cover but rather to estimate individual perceptions of such change. Such perceptions are useful for capturing individual place-value attachment and fine-scale changes in tree and branch density in Pemba, Tanzania (Clark, Hamad, et al., 2023; Zahor, 2020).

Over an 8-month field season in 2022, we intended to implement this methodology in each of the 49 shehia on the island that contained mangrove forest, representing a geographically complete census rather than a sample (Clark, Salim, et al., 2023). However, we ultimately collected data from 43 shehia, rather than all 49 (Figure 1). The 6 shehia not included in the study were excluded due to time and funding constraints, rather than for any systematic purpose. In each of these 43 shehia, we used community household registries to randomly select 5 adult men and 5 adult women to participate in this activity, which resulted in a final sample size of 423 after dropping 7 responses due to incomplete survey information.

The participatory mapping activity began with a workshop format in which we established a shared understanding of our goals and facilitated a simple mapping orientation exercise because most of the local population does not regularly use maps to navigate their environment. Men and women completed this task together as is standard in schools, workplaces, and other aspects of life in Pemba. Each participant was provided with a gridded base map of their community, with towns, roads, bodies of water, cultural landmarks (e.g., mosques), and any protected areas labeled to help with orientation. Each grid cell corresponded to a 0.5-km^2 area. After a further orientation,

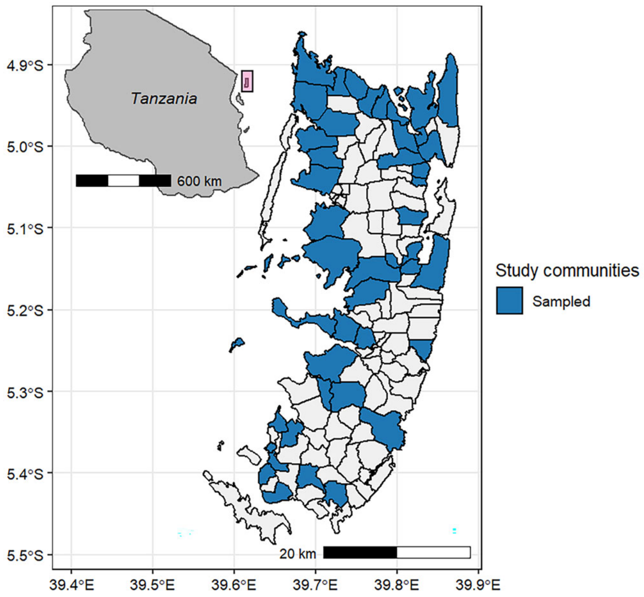

FIGURE 1 Wards (shehia) (blue) on Pemba (large map), Tanzania, where community members were surveyed regarding their perceptions of forest change, intergroup mangrove theft, and their engagement with community-based conservation (inset, location of Pemba relative to Tanzanian mainland).

we asked participants to identify their own place of residence and other important locations to verify their basic understanding of the map. The final group task was to mark (initially with buttons until consensus was reached, then with a pen) each grid cell with mangrove forest. Women and men, as is conventional in mixed-gender meetings in strongly Islamic and patriarchal cultures such as Pemba, generally chose to work in separate subgroups. Research staff communicated between subgroups to rectify inconsistencies until all groups agreed on one accurate community map. Thus, the workshop-style component of the participatory mapping activity ended once each participant was adequately oriented to a gridded map of their community and each grid containing mangrove forest was marked identically across all participant maps (Figure 2).

For the remainder of the participatory mapping activity and the questionnaire completion that followed, all participants responded individually. With the consensus map of mangrove locations in hand, each participant was asked to indicate, for each grid cell containing mangrove, whether they felt the tree cover in that area had increased, stayed the same, or decreased in the last year. This 1-year recall period was selected to reduce the risk of seasonal confounds that could be introduced from a shorter time frame and the loss of recall accuracy that could be introduced by a longer time frame, given that large mangrove cutting events can happen on the order of days to weeks. Participants could also indicate that they were not sure about how mangrove cover had changed. Throughout the activity, research staff emphasized that participants should feel free to use this indication of uncertainty rather than guessing an answer. Participants who felt they were unable to become oriented with the map indicated uncertainty for every grid cell. An example of a completed map is in Appendix S1. The total number of grid cells in which a participant indicated that the mangrove cover had declined in the last year was tallied to produce an estimate of the perceived percent decline in community mangrove forest cover for each respondent.

Questionnaire

Following the participatory mapping activity, all participants completed an individual questionnaire with the help of research staff. The purpose of this questionnaire was to elicit responses regarding conservation behavior and preferences, perceived pressure of theft from outsiders, and general demographic information. Specifically, participants used a binary response to indicate whether or not they ever engaged in patrols to protect community mangrove forests from theft from outsiders. If yes, participants listed the number of mangrove patrols they estimated they had performed in the past month. Participants also indicated their preferences for harvest limits on themselves and other community members who rely on community mangroves to collect fuelwood. This outcome variable was collected as an integer value corresponding to the number of fuelwood bundles that they would like to limit themselves and their fellow community members to harvesting each month.

To quantify individuals' perceptions of theft from outsiders in their community mangroves, we asked respondents to estimate the number of outsiders they believe come to their shehia to harvest fuelwood each week. We asked participants to provide their best guess of where these individuals generally come from to ensure they were describing individuals from outside their shehia, rather than a smaller village-level group. Finally, we recorded the gender and occupation of each participant through multiple-choice questions and asked whether they were a member of a village or shehia conservation committee with a binary choice question. The questionnaire is in Appendix S2.

Analyses

We performed 2 separate statistical analyses of the collected data. The first (model 1 [Equation 1]) was designed to estimate the observed effects of perceived decline of community mangroves and perceived mangrove theft on preferences for in-group harvest limits on fuelwood. In accordance with current best practices for causal inference, we constructed a directed acyclic graph to determine what parameters needed to be controlled for to estimate the direct effects of interest (Table 1) (McElreath, 2020; Pearl, 2009; Westreich & Greenland, 2013). In this process, we explicitly described the complete hypothesized causal pathway between our predictors and outcome of interest and identified other variables and associations between them that may affect the outcome through separate causal paths (Pearl, 2009). We then controlled for these alternative causal paths to capture accurate effect sizes for our direct effects of interest.

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FIGURE 2 Example of the participatory mapping activity used in the study of Pemba (large map), Tanzania, community perceptions of forest change, intergroup mangrove theft, and their engagement with community-based conservation. Photo shows H.M.H. explaining the individual response portion of the activity.

TABLE 1 Variables used in regression analyses to examine the effects of perceptions of forest change and intergroup competition on mangrove patrolling behavior and preferences for limiting fuelwood harvests.

Variable	Source	Type	Estimand or control	Model
Predictors				
Occupation	Questionnaire	Categorical	Control	Model 1 (Equation 1)
Perception of community mangrove change in the past year	Participatory mapping activity	Integer of 0.5-km^2 areas decreasing cover	Estimand	Models 1 (Equation 1) and 2 (Equation 3)
Perceived number of outsiders stealing from community mangroves per week	Questionnaire	Integer	Estimand	Models 1 (Equation 1) and 2 (Equation 3)
Interaction between perceived mangrove change and perceived mangrove theft	Questionnaire & participatory mapping activity	Not applicable	Estimand	Model 1 (Equation 1)
Size of community mangrove area	Participatory mapping activity	Integer of 0.5-km^2 areas	Control	Models 1 (Equation 1) and 2 (Equation 3)
Community included in Redd+ initiative	Previous research	Binary	Estimand	Models 1 (Equation 1) and 2 (Equation 3)
Member of shehia (ward) or village conservation committee	Questionnaire	Binary	Control	Models 1 (Equation 1) and 2 (Equation 3)
Gender	Questionnaire	Categorical	Control	Model 2 (Equation 3)
Outcomes				
Preferred monthly community fuelwood harvest limit	Questionnaire	Integer of fuelwood bundles	Outcome	Model 1 (Equation 1)
Number of mangrove patrols conducted in the past month	Questionnaire	Integer	Outcome	Model 2 (Equation 3)

We used a Poisson distributed generalized linear mixed model operationalized in a Bayesian framework to estimate the direct effects of interest (estimands) (Table 1; Appendix S3). The Poisson distribution is appropriate in this case because the outcome data (preferred allowable fuelwood harvest) were discrete counts and were not overdispersed (Appendix S4). We estimated the independent effects of perceived theft pressure ($\beta 1$) and mangrove loss ($\beta 2$); the effect of the interaction of these 2 predictors ($\beta 3$); and whether the shehia was one of the 18 exposed to the failed REDD+ intervention ($\beta 4$) on individuals' preferred harvest limits from community mangrove forests. We hypothesized that multiplicative interaction of perceived theft pressure and mangrove loss contributes substantially to individual preferences for conservation on the basis of the conditional dynamic identified by the theoretical work of Andrews et al. (2024). Based on assessment of the causal paths in the directed acyclic graph (Appendix S3), we controlled for participant occupation ($\beta 5$), size of the community mangrove area ($\beta 6$), and whether or not the participant was a member of a village or shehia conservation committee ($\beta 7$). Finally, because we used a mixed model, we estimated a varying intercept ($\boldsymbol{\beta} 0_j$) for each of the 43 study shehia and for the global intercept ($\alpha 0$). This statistical model was as follows:

$$
\begin{aligned}
Y_{ij} &\sim \text{Poisson}(\mu_{ij}) \\
\mu_{ij} &= exp\big(\alpha 0 + \beta 0_j + \beta 1 \cdot \text{theft}_i + \beta 2 \cdot \text{MangDecl}_i \\
&\quad + \beta 3 \cdot \text{theft}_i \cdot \text{MangDecl}_i + \beta 4 \cdot \text{REDD}_i + \beta 5 \cdot \text{occupation}_i \\
&\quad + \beta 6 \cdot \text{MangArea}_i + \beta 7 \cdot \text{CommitteeMemb}_i\big) \\
\beta 0_j &\sim \text{Norm}(0, \sigma)
\end{aligned} \tag{1}
$$

where μ is the deterministic mean, σ is the standard deviation, Y is the observed preferred harvest limit, theft is the perceived of mangrove theft, MangDecl is the perceived percent decline in community mangroves, REDD represents whether the respondent's community was involved in the REDD+ scheme, occupation is the primary occupation of the respondent, MangArea is the size of the community mangrove area, and CommitteeMemb represents whether the respondent is a member of a village or shehia conservation committee.

The second analysis we conducted (model 2 [Equations 2 & 3]) estimated the effects of perceived mangrove theft from outsiders and forest cover loss on respondents' reported engagement in community mangrove patrols. Mangrove patrols are conducted on a relatively ad hoc basis by groups of specific individuals. The degree of participation of those individuals varied greatly. To adequately capture this data generating process, we first accounted for how the set of predictors affected how likely a respondent would be in the group of specific individuals who conducted patrols and, thus, report engaging in mangrove patrols ever (Bernoulli distributed with probability θ). If a respondent did engage in mangrove patrols, we assessed how these predictors affected the number of patrols the respondent engaged in each month (zero-truncated negative binomial distribution with mean μ and dispersion ϕ). Statistically, this took the functional form of a hurdle process, with the probability mass function shown in Equation (2) (Zuur et al., 2009). The negative binomial distribution is appropriate in this case because the outcome data were discrete counts and were overdispersed (i.e., the dispersion is greater than the sample mean).

$$
P_{\text{HurdleNegBinom}}(y|\pi,\mu,\theta) = \begin{cases} \pi, & y = 0 \\ (1-\pi)\cdot P_{\text{ZeroTruncNegBinom}\}(y|\mu,\theta)}, & y > 0 \end{cases}, \tag{2}
$$

where P is the joint probability function determining y, the observed number of patrols respondents engaged in, and π is the probability of not engaging in patrolling behavior at all.

Again, for this analysis, we selected the parameter set necessary to estimate the direct effects of interest by assessing the causal paths in the directed acyclic graph depicting our conceptual understanding of the system (Appendix S3). Through this procedure, we concluded that to estimate the effect of perceived theft ($\beta 1$), perceived forest decline ($\beta 2$), and exposure to REDD+ ($\beta 3$) on patrolling behavior, we had to control for the size of the community mangrove area ($\beta 4$), gender of the participant ($\beta 5$), and whether or not the participant was a member of a village or shehia conservation committee ($\beta 6$).

We did not include a multiplicative interaction term between the effects of perceived theft and perceived forest decline in this statistical model (Equation 3) as we did in the statistical model that assessed the effect of these predictors on preferences for limiting fuelwood harvests (Equation 1):

$$
Y_{ij} \sim \text{HurdleNegBinom}\left(\pi_{ij}, \mu_{ij}, \phi\right), \quad \pi_{ij} = \frac{\exp(\eta_{ij})}{1+\exp(\eta_{ij})}, \tag{3}
$$

$$
\begin{aligned}
\eta_{ij} &= \alpha 0^{\eta} + \boldsymbol{\beta} 0_j^{\eta} + \beta 1^{\eta} \cdot \text{theft}_i + \beta 2^{\eta} \cdot \text{MangDecl}_i \\
&\quad + \beta 3^{\eta} \cdot \text{REDD}_i + \beta 4^{\eta} \cdot \text{MangArea}_i + \beta 5^{\eta} \cdot \text{gender}_i \\
&\quad + \beta 6^{\eta} \cdot \text{CommitteeMemb}_i,
\end{aligned}
$$

$$
\mu_{ij} = \exp\Big(\alpha 0^{\mu} + \boldsymbol{\beta} 0_j^{\mu} + \beta 1^{\mu} \cdot \text{theft}_i + \beta 2^{\mu} \cdot \text{MangDecl}_i + \beta 3^{\mu} \cdot \text{REDD}_i + \beta 4^{\mu} \cdot \text{MangArea}_i + \beta 5^{\mu} \cdot \text{gender}_i + \beta 6^{\mu} \cdot \text{CommitteeMemb}_i\Big),
$$

$$
\boldsymbol{\beta} 0_j \sim \text{Norm}(0, \sigma),
$$

where gender represents the gender of the respondent and Y represents the number of patrols the respondent reported engaging in.

We omitted the multiplicative interaction term because we had no a priori theoretical basis for including it (Gelman & Loken, 2013; Tredennick et al., 2021). In this analysis (Equation 3), we included the gender of each participant instead of the participant occupation as in Equation (1) because gender affects occupation and patrolling behavior; thus, including both gender

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and occupation would have resulted in estimating the effect of gender along 2 separate causal paths.

In statistical model 1 (Equation 1), we did not assume that participant gender affects preferences for in-group harvest limits, whereas we did assume that gender affects patrolling behavior. We again used a Bayesian mixed model, where we estimated a varying intercept for each of the 43 shehia ($\beta 0^{\eta}_{j}$ and $\beta 0^{\mu}_{j}$). This statistical model is formalized in Equation (3), where we estimated independent coefficient values for each parameter for both the Bernoulli (η) and zero-truncated negative binomial (μ) components. This analysis resulted in separate estimates for the effect of each predictor on the likelihood that respondents engage in patrols ever, and, if so, how many they reported engaging in in the past month.

For both statistical models, we used weakly regularizing priors (Gelman et al., 2008) to produce conservative coefficient estimates. Both statistical models exhibited adequate convergence of Markov chains, adequate posterior predictive capacity, and $\hat{R}$ values equal to 1 for all coefficients (Appendix S4). All data for this project and the R and STAN code used in these analyses are available from https://github.com/matthewclark1223/ParticipatoryMappingProj.

In interpreting the outputs of these empirical analyses, we considered any parameter estimate in which the central 0.9 quantile of the posterior mass did not overlap zero as credible. This cutoff, although arbitrary, indicates that at least 95% of all samples from the posterior were on one side of zero and therefore there was at least a 0.95 probability of a true effect given the data (Goodrich et al., 2020; McElreath, 2020).

As in all statistical analyses, the validity of the output of the 2 described analytical procedures relied on several key assumptions. The primary assumption was that we identified all important drivers of the 2 outcomes of interest—preferences for harvest limits and patrolling behavior—and had correctly depicted the causal relationships between them. This assumption is reasonable given that our analyses were based on a priori hypotheses derived from theoretical modeling work, extensive ethnographic work in this system, and relevant literature (Gelman & Loken, 2013). The second assumption is of the independence of observations. This assumption was also met, given that all participants responded independently regarding their personal behaviors and preferences and that we accounted for group-level differences and confounds by assigning a group-level random intercepts as described above.

RESULTS

Preferences for fuelwood harvest limits

We find strong evidence that the interaction between individual perceptions of mangrove degradation and perceptions of mangrove theft from outsiders was significantly associated with preferences for fuelwood harvest limits from community mangroves. Two thousand draws from the posterior distribution indicated a 0.98 probability that the interaction term was positively associated with the outcome as indicated by the lack of overlap between the 90% credible interval (CI) and the zero line in Figure 3.

We used the parameter estimates from this statistical model to calculate the expected conditional effect of changes in perceived theft and mangrove decline on reported preferences for fuelwood harvest limits given a mean value of all other predictors. In respondents who reported no perceived theft in their community mangrove forests, an increase in perceived mangrove decline from 0% to 50% of the community mangrove area resulted in a median expected decrease in preferred harvest limits from 2.74 bundles of firewood (90% CI 1.39–5.48) to 2.37 bundles of fuelwood (90% CI 1.20–4.75). Respondents who reported that 100% of their community mangroves were declining in cover reduced their fuelwood harvest limits to 2.05 bundles (90% CI 1.02–4.17).

The interaction term indicated that this trend was reversed in individuals who perceived high levels of mangrove theft from outsiders. In these respondents, an increase in perceived mangrove decline from 0% to 50% of the community mangrove area was associated with an expected loosening of preferred harvest limits from 1.26 bundles of fuelwood (90% CI 0.54–2.92) to 2.75 bundles of firewood (90% CI 1.33–5.75). Respondents who perceived the highest levels of theft and reported that 100% of the community mangrove area was declining were expected to report a preference for a harvest limit of 6.07 bundles (90% CI 2.34–15.50), a nearly 5-fold increase from those who perceived that 0% of the community mangrove area was in decline (Figure 4).

Finally, shehia that were part of the failed REDD+ initiative on the island showed a slight increase in preferred harvest limits compared with individuals in shehia where the REDD+ project was never introduced (Figure 3). This effect was, however, highly uncertain and not credible because the proportion of samples >0 was 0.79, representing a 0.79 probability of a true effect given our data and indicated by the overlap between this effect and the zero line in Figure 3.

Mangrove patrolling behavior

The coefficient estimates from the regression described in statistical model 2 (Equations 2 & 3) showed that observed patrolling behavior was likely driven by different processes than were preferences for restricting fuelwood harvests. The Bernoulli (binary) component of the statistical model indicated that neither perceived mangrove theft nor perceived mangrove decline was associated with whether individuals reported engaging in mangrove patrols at all. The posterior distribution of the Bernoulli component resulted in a noncredible 0.87 probability that perceived theft is associated with an increase in the likelihood that individuals ever engaged in mangrove patrols. Perceptions of mangrove decline had essentially no relationship with likelihood of patrolling behavior (Figure 5). Similarly, perceptions of mangrove decline and theft also had essentially no relationship with the number of patrols an individual engaged in (Figure 6).

Men were more likely than women to report engaging in patrols and to report engaging in a greater number of patrols

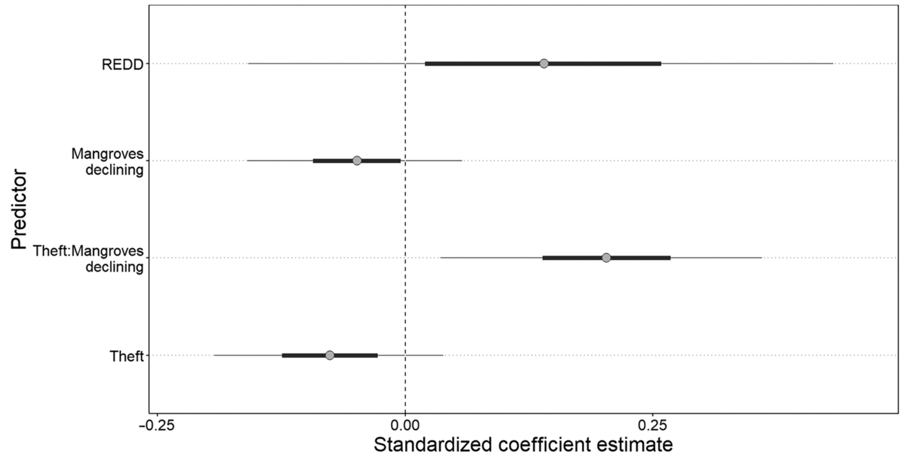

FIGURE 3 Standardized coefficient estimates from the statistical model shown in Equation (1) used to estimate the observed drivers of preferences for limiting fuelwood use (thick bars, inner 50% of the posterior distribution; thin bars, inner 90% of the posterior distribution [credible interval]; REDD, community involvement in the REDD+ carbon accreditation program).

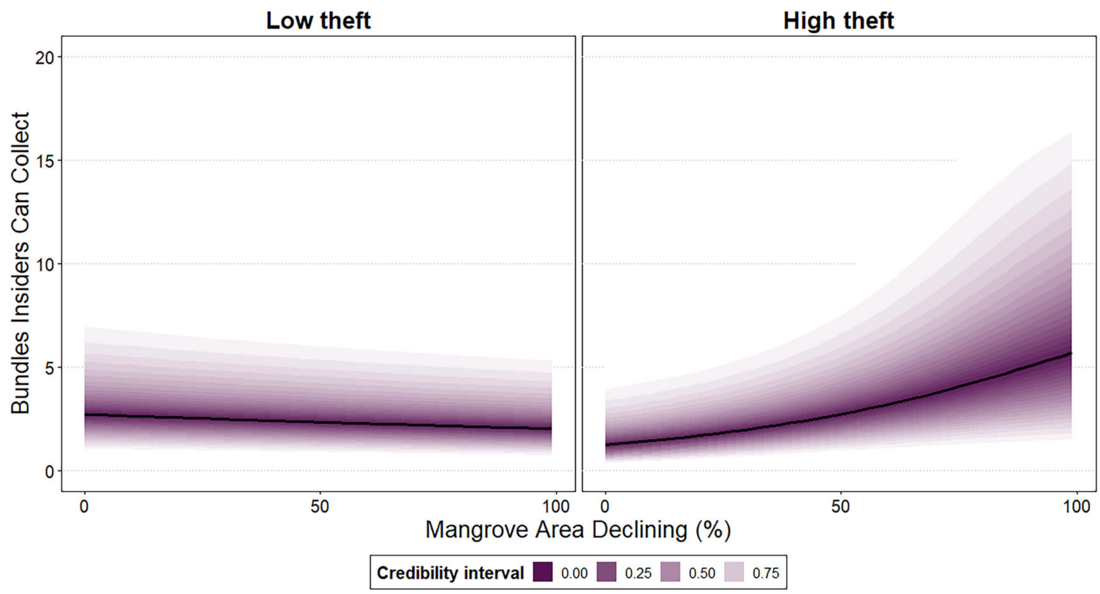

FIGURE 4 Conditional effect of the interaction of individual perception of mangrove decline and perceived intergroup theft on individual preference for in-group fuel-wood harvest limits (low theft, effect of perceived mangrove decline when perceived theft was near zero; high theft, effect when perceived theft was at the highest recorded value; conditional effect, effect of these predictors at a mean value of all other predictors; black lines, median model estimates; shading, credible interval).

(Figures 5 & 6). Given a mean value for all other predictors, the probability that women reported engaging in patrols at all was 0.17 (90% CI 0.13–0.21) and the probability that men reported engaging in patrols at all was 0.37 (90% CI 0.32–0.43). Of men and women who reported patrolling, the median number of patrols performed by each gender in the last month was 6 and 3, respectively. Lastly, membership in a shehia or village conservation committee was positively associated with individuals reporting going on patrols at all (Figure 5) but was not credibly associated with the number of patrols they reported engaging in because 91% of parameter estimates were >0 (Figure 6).

The outputs of this statistical analysis also indicated that past community exposure to REDD+ was associated with a decrease in the probability of individual engagement in mangrove patrols. Specifically, there was a 0.96 probability that individuals from shehia selected for the failed REDD+ project were less likely to report engaging in mangrove patrols at all compared with those from shehia not exposed to the REDD+ project (Figure 5). Given a mean value for all other predictors, the probability that individuals in shehia that were part of the REDD+ project reported engaging in patrols at all was 0.17 (90% CI 0.11–0.25), compared with a 0.32 probability (90% CI 0.27–0.37) for individuals from shehia not exposed to REDD+.

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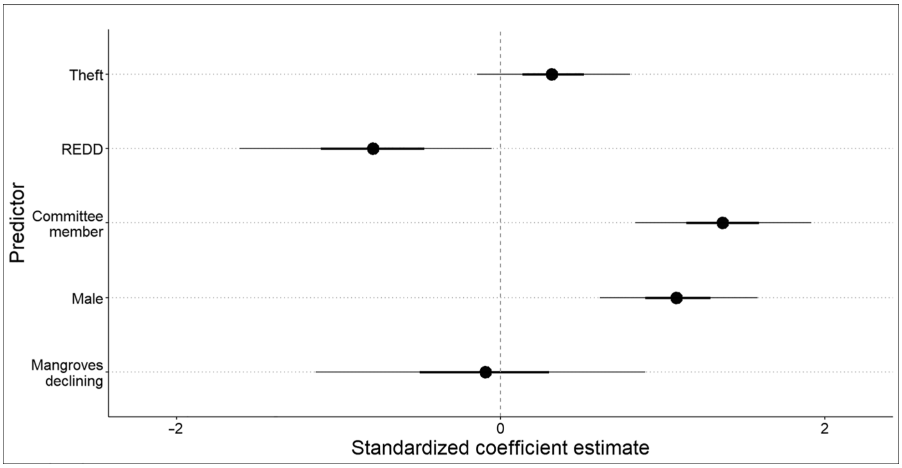

FIGURE 5 Standardized coefficient estimates for the Bernoulli component of the statistical model estimating the observed effect of these predictors on patrolling (i.e., voluntary patrols to safeguard community mangroves) behavior (Equation 3) (thick bars, inner 50% of the posterior distribution; thin bars, inner 90% of the posterior distribution [credible interval]; REDD, community involvement in the REDD+ carbon accreditation program). The Bernoulli component estimates the effect that the predictors have on whether or not individuals engage in patrolling behavior at all.

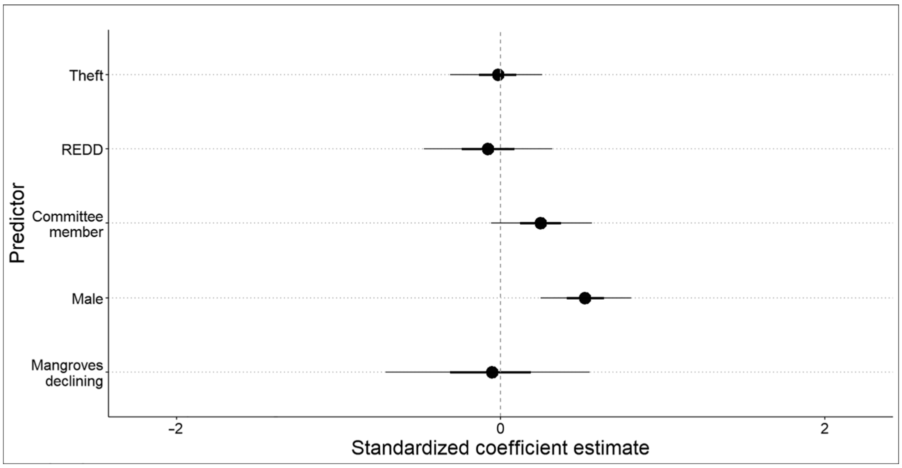

FIGURE 6 Standardized posterior estimates for the zero-truncated negative binomial component of the statistical model estimating the observed effect of these predictors on patrolling (i.e., voluntary patrols to safeguard community mangroves) behavior (thick bars, inner 50% of the posterior distribution; thin bars, inner 90% of the posterior distribution [credible interval]; REDD, community involvement in the REDD+ carbon accreditation program). The zero-truncated negative binomial component estimates the effect that the predictors have on the number of patrols that individuals engage in.

However, this predictor was not associated with the number of patrols that individuals engaged in (Figure 6).

DISCUSSION

We empirically examined community responses to perceived deforestation, not because communities were necessarily the primary drivers of forest loss, but because community-based conservation is an increasingly important strategy for effectively and equitably combating natural resource degradation worldwide (Bebbington et al., 2018; Calfucura, 2018). We uncovered an important interaction between perceptions of environmental degradation and exposure to resource theft on 2 different types of conservation behaviors—preferences for harvest limits and community patrols. Put simply, individuals who were not exposed to theft while simultaneously experiencing resource decline were motivated to protect that dwindling resource. In contrast, individuals who were exposed to high levels of theft while simultaneously experiencing resource decline were motivated to weaken harvest limits, presumably in a race to grab what they could while the resource was still available.

We also found that perceived mangrove degradation and theft from outsiders did not significantly affect individual engagement in patrols to exclude outsiders from stealing mangroves from community forests. Instead, this behavior was performed primarily by specific members of the community. Thus, as theft increased, there was relatively no mechanism to reduce it. Because theft is left largely unregulated, a race-to-the-bottom phenomenon caused in-group members to also harvest rapidly from community forests.

Relation to and deviation from theory

Our findings, in combination with the theoretical development by Andrews et al. (2022, 2024), help detail the mechanisms underlying Ostrom's (1990) first tenet that reliable boundaries are critical for sustainable common-pool resource management. Our results support the theoretical intuition that positive endogenous changes in community self-regulation can follow in the wake of strong boundaries. Our evidence also supports the counter claim that a lack of effective boundaries may degrade intrinsic motivations to safeguard natural resources, making boundaries a prerequisite for common-pool resources sustainability.

This research contributes to filling the gap identified by Meyfroidt (2013) that little is known about how individuals use conservation behaviors to respond to perceived environmental change. These results revealed that different types of conservation behaviors were likely affected differently by perceived environmental change. Although preferences for limiting resource use were greatly affected by perceptions of environmental change and its causes, behaviors to enforce resource boundaries were not. We speculate that because patrolling behavior is a visible action, pressure to adhere to local norms may operate more strongly on this outcome than on preferences for allowable community harvests that may be privately held. Rule enforcement can also be dangerous and socially costly, or in the case of women, culturally inappropriate. Thus, it may be seen as the exclusive purview of a specific group of individuals. For example, women and nonconservation committee members in our sample were much less likely to report engaging in mangrove patrols than male committee members, even if they had identical perceptions of mangrove theft and decline and a similar history with conservation programing.

There is a growing body of literature on the adoption of conservation behaviors and scaling of conservation projects to which this insight might be applicable (e.g., Clark et al., 2022; Mahajan et al., 2020; Mills et al., 2019). For example, theoretical models and analyses of empirical data may assume different social and ecological drivers of different classes of conservation actions. This intuition is supported more generally by findings from cultural evolutionary studies that show that the emergence of altruistic cooperation within groups is driven by fundamentally different processes than the emergence of altruistic punishment (Boyd et al., 2003). Research into the adoption of conservation behaviors may then benefit by defining categories of actions, such as in-group regulatory behaviors and out-group exclusionary behaviors or predominantly environmentally driven versus socially driven actions, among many other possible categorizations.

One interesting and somewhat unexpected important predictor emerged for fuelwood harvest limits and mangrove patrolling. Past community exposure to the failed REDD+ project on the island was associated with reduced probability of engagement in mangrove patrols and showed a noncredible (probability = 0.79), yet interesting, positive association with individual preferences for fuelwood harvest limits (these individuals preferred less stringent harvest limits). We hesitate to draw strong conclusions from these data because this effect was not the primary question of the study (Tredennick et al., 2021). Yet, these trends are well aligned with theories regarding motivational crowding (Frey & Jegen, 2001; Rode et al., 2015). Along these lines, we speculate that past promises of payments for conservation behaviors, such as forest patrols, may have affected individuals' expectations regarding the payoffs they should receive from these behaviors, even in the absence of ever actually receiving such payments (Cinner et al., 2021). Although there are other indications from a larger sample of individuals and broader environmental and behavioral contexts (not limited to mangroves or patrolling) collected in Pemba in 2017, that preferences for conservation persisted in communities exposed to the REDD+ intervention (Andrews & Borgerhoff Mulder, 2023). This effect may then be context dependent and perhaps limited to patrolling behaviors rather than applicable to proenvironmental behaviors broadly.

Management implications

As the negative impacts of climate change continue to affect communities of small-scale producers around the world, conservation actions, such as mangrove protection and restoration, are increasingly posited to buffer individuals against the worst impacts (Cohen-Shacham et al., 2016; Sidik et al., 2018). We found that community uptake of conservation may be greatly hindered by a lack of clear social or physical boundaries to protect the benefits accrued by such actions. Yet, actions to exclude out-group members from community resources were costly. Our results showed that they were so costly that even when individuals perceived them as necessary, they would not perform them without some degree of social license (e.g., membership in a shehia conservation committee). Thus, our results suggest that support in the form of training and funding for community-based conservation initiatives specifically to demarcate and protect resource boundaries may increase their ability to combat the negative impacts of climate change through conservation. Such a policy may have dual benefits, directly stopping harvests from outsiders and supporting the endogenous emergence of sustainable in-group norms.

When gains from conservation behaviors were not eroded by outsiders, we found that individuals responded to perceived environmental degradation by supporting stricter limits on resource harvests. This result is promising for the prospect of meeting global conservation goals through community-based initiatives. The status of many resources is, however, not easily observable to local communities and even observed changes may be forgotten as individuals' baselines for resource condition shift (Papworth et al., 2009). We emphasize then that supporting communities in effectively monitoring both local resources and the social benefits gained from protecting them is critical for the success of community-based conservation (Jones et al., 2013; Salerno et al., 2021). Importantly, however, supporting certain groups of individuals to perform exclusionary monitoring of resources must be done with caution to avoid perpetuating group social inequities or unjust systems of resource tenure (Kockel et al., 2020; Robinson et al., 2018). Finally, we want to explicitly avoid conflating the suggestions above with calls to exclude communities from accessing forest resources through the establishment of boundaries (e.g., protected areas). The demarcation of access and use rights over resources suggested here are intended to support communities in establishing durable institutions of natural resource monitoring and management so that those resources may continue to provision resources for harvest.

Our results regarding the effect of the failed REDD+ initiative are exploratory because this phenomenon was not the intended subject of study, but the results may signal an important trend. Our findings indicated that past, undelivered promises of payments for ecosystem services can have lasting negative impacts on community members' willingness to voluntarily engage in community-based conservation. Although we do not know the exact mechanism for this effect (e.g., motivational crowding, resentment, etc.), these results support the common sentiment that well-reasoned exit strategies must be established before a conservation project is implemented.

Limitations and future work

The primary limitation of our work is the nonrandom exclusion of the 6 shehia due to time and funding constraints. However, our extensive ethnographic experience in Pemba does not lead us to believe that these shehia should fundamentally differ from those sampled in a way that would alter the results of this research. Specifically, these shehia do not greatly differ from those sampled in the importance of mangroves to the community, exposure to REDD+, or rates of environmental change. It is possible, however, that the nonrandom exclusion of these shehia biased our results in unknown ways and could limit the applicability of our findings to those shehia that were not sampled. Although we did not foresee the incomplete sampling of the 49 total shehia that contain mangrove forest at the onset of the data collection, the data collection scheme could have been improved by randomizing the order in which the shehia were visited.

Another key limitation is that we relied on self-reported conservation preferences and behaviors for our outcomes of interest. The insights provided here would be bolstered if the realized conservation behaviors of participants could be observed. For example, given the design of this study, we were unable to determine whether individuals who were members of conservation committees were actually more likely to perform patrols than nonmembers or if, instead, they were only more likely to report that they engaged in patrols. An example of productive future work might be to perform a similar participatory mapping activity with a random sample of a community after researchers host a tree planting activity or other conservation-oriented event. Researchers may then record whether respondents attended the activity and relate this actual conservation behavior to the predictor variables of interest.

Although not a direct limitation, this study would have benefited from the inclusion of qualitative interviews with key community members, such as elders, to contextualize and even validate the quantitative findings. By performing more in-depth exploration of the observed dynamics in shehia with the highest and lowest reported rates of forest cover loss and intergroup theft, we might have further delineated the mechanisms of behavioral change and even forest change, for example. Additionally, inclusion of qualitative insights from conservation leaders, such as nongovernmental organization staff, government workers, or shehia leaders, may have yielded more nuanced interpretations of the factors that drive individuals to adopt or abandon conservation behaviors.

The final key limitation of this study is that our measure of REDD+ exposure was at the community level, whether the shehia was one of the 18 selected for the intervention, and our outcomes were at the individual level. This finding would be strengthened by measuring individual exposure to REDD+ at the individual level as well. Conservation science would benefit from a comprehensive examination of the effects that failed or terminated conservation projects have on local conservation preferences and behaviors (e.g., Chervier et al., 2019; Massarella et al., 2018).

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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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