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National-level evaluation of a community-based marine management initiative

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Community-based approaches to conservation and natural resource management are considered essential to meeting global conservation targets. Despite widespread adoption, there is little understanding about successful and unsuccessful community-based practices because of the challenges of designing robust evaluations to estimate impacts and analyse the underlying mechanisms to impact. Here we present findings from a national scale evaluation of the 'locally managed marine areas' network in Fiji, a marine community-based management initiative. Using data from 146 villages selected using matching methods, we show that engagement in the Fijian locally managed marine areas network leads to improvements in all mechanisms hypothesized to generate conservation outcomes (participation, knowledge, management and financial support). Yet these mechanisms translate to few social outcomes and have no effect on the perceived ecological health of a village's fishing grounds. Our findings show that practitioners may need to carefully evaluate and adapt the mechanisms that they expect will generate impact from community-based projects to improve outcomes for people and the rest of nature.

Community-based natural resource management (CBNRM) has long been hailed as a solution to the failure of top-down regulation to stem ecological degradation[1,2] and is increasingly highlighted as critical to achieving global conservation targets[3–5]. This decentralized management model—in which natural resource rights are partly or fully devolved to local communities—typically aims to advance conservation and/or resource management objectives while prioritizing local values and needs[6,7]. Given the spread of community-based initiatives around the world—and concerns about their performance[8–10]—it is essential to identify what works (and what does not work) in CBNRM to inform the design and implementation of effective initiatives that help achieve global conservation targets in ways that benefit local communities.

An extensive literature has contributed towards this aim by examining the social and ecological outcomes of CBNRM projects (for recent meta-analyses, see refs. 6,11,12), with the evidence suggesting mixed results. Yet few studies[13–17] use robust designs that control for confounding to estimate impact. In evaluating CBNRM projects and initiatives, it is essential to ensure that the observed effect is not due to unaccounted-for factors that also determine participation in the project. Examples of such confounding factors include: resource pressure, size of resource to be managed, and access to external support, all of which may influence whether a village participates in a CBNRM project as well as how it performs. Failure to control for the effects of these confounders can lead to incorrect assessments of impact.

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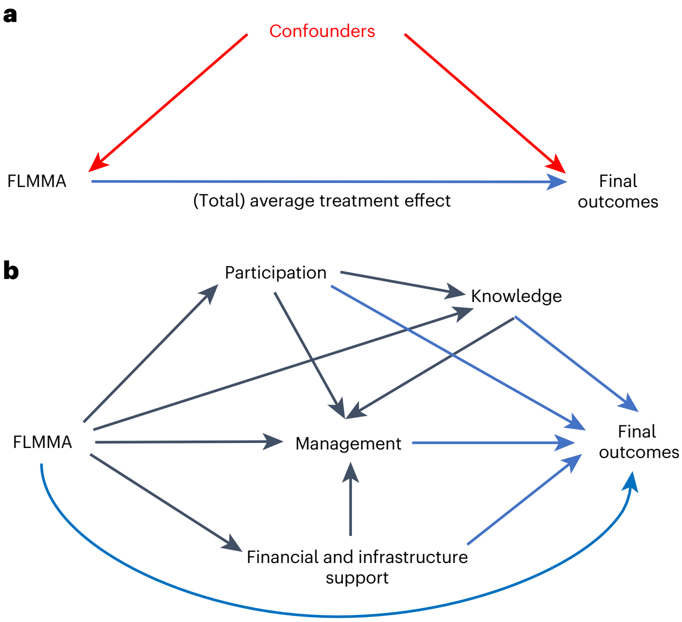

Fig. 1 | Directed acyclic graphs (DAGs) of FLMMA impact on final outcomes and hypothesized mechanisms to impact. Arrows between variables indicate direct causal effects. **a**, A basic DAG depicting the overall (total) average treatment effect of FLMMA village membership on final outcomes, controlling for confounders (in red); this corresponds to a simple analysis of impact that does not account for mechanisms. **b**, An elaborated DAG showing the mechanisms that are hypothesized to mediate the effect of FLMMA on the final outcomes, and interactions between these (for details, see Methods). Confounders are not shown in **b**. for ease of viewing, but are controlled for on all exogenous and endogenous variables in both models. Black arrows show pathways to and between intermediate outcomes/mechanisms; the causal effects of these pathways are constant irrespective of the final outcome. Blue arrows show pathways leading to final outcomes; the causal effects of these blue arrows vary by final outcome.

Understanding what works in CBNRM does not only imply estimating impact, but also understanding the mechanisms through which community-based initiatives cause—or fail to cause—the desired impacts[18]. Although causal models have been proposed explaining how community-based approaches may lead to final outcomes[18,19], so far no studies have quantified these mechanisms. Indeed, we have identified only three studies in the wider conservation literature that quantify mechanisms, with respect to protected areas[20], marine reserves[21] and conservation incentives[22], and findings broadly suggest that the hypothesized mechanisms do not always work as expected. By examining how CBNRM initiatives succeed or fail, decision-makers will be better able to co-design and implement locally appropriate and effective programmes at scale[23].

Our study contributes to these aims, firstly by measuring the impact of a CBNRM initiative on a range of social and economic outcomes, and on perceptions of ecological health, using robust methods that control for confounding; secondly, by estimating the effect of key mechanisms hypothesized to mediate the effect of the CBNRM initiative on the final outcomes of interest. To do this, we present findings from the first robust, national-scale evaluation of a marine CBNRM initiative—the 'locally managed marine areas' (LMMA) network initiative in Fiji.

LMMAs are areas of nearshore waters, and their associated coastal and marine resources, that are managed at a local level by coastal communities with support from partner organizations[24–26]. Partners (for example, non-governmental organizations (NGOs)) typically provide guidance, information and technical support to villagers for improved monitoring and management of local coastal resources[27,28]. Fiji has one of the most extensive networks of LMMAs in the world, currently estimated to span over 350 communities across 12 provinces (FLMMA 2020 database). These LMMAs are supported by a variety of NGOs and a university, and there is a Secretariat that coordinates responses to village requests for support. This network of LMMAs and partners is known as the 'Fiji LMMA network' (hereafter, FLMMA) since 2001. It is governed by a Board of Trustees and Councillors and an Executive Committee with representatives from partner NGOs, government agencies and member communities, and is chaired by the Permanent Secretary of the Ministry of iTaukei Affairs. The Secretariat team (including a national coordinator, support and technical staff, community engagement officers, and provincial and community representatives) implements decisions made during annual meetings involving all members as well as the Board of Trustees and the Executive Committee. The aim of FLMMA is to enhance adaptive management of marine resources in villages so as to generate livelihood and ecological benefits[29]. It is a learning network, in which members are encouraged to share knowledge generated through their experiences with fisheries management practices[29]. Villages opt in to joining the FLMMA network and establishing LMMAs in their customary fishing grounds (known as '*iqoliqoli*' in Fiji); thus, network membership is voluntary.

Given that villages self-select into FLMMA, it is likely that they differ from non-member villages in ways that also influence how they perform with respect to different outcomes. To minimize the effect of such potential confounding, we used propensity score matching to select FLMMA and non-FLMMA villages that are similar with regard to potential confounders (Methods). Data were collected from these villages using key informant group interviews with the main social groups (leaders, fishers, women and youth) (Supplementary Information 1). Using this data ($n = 146$), we identify whether participation in the FLMMA network has led to improvements in key outcomes of importance to villages (recorded in ref. 30 and ref. 27), as well as additional outcomes of importance to CBNRM more generally[6,11,13,31]. The final outcomes we study here include: economic wellbeing and livelihoods, food security, subjective wellbeing, perceived ecological conditions and perceived benefits from management (Methods; Extended Data Table 1 for indicators; Supplementary Information 2 for how indicators were operationalized).

Given the lack of longitudinal or pre-intervention data on outcomes, we estimate impact by comparing post-intervention outcomes of FLMMA and non-FLMMA villages without accounting for changes over time. This analysis is represented in Fig. 1a. Although recent research suggests that difference-in-difference (also known as 'before-after-control-intervention') designs may be more suitable to estimate impacts from conservation policies[32], single difference estimators with matching have been found to perform similarly in replicating results of a randomized controlled trial[33]. In the absence of longitudinal data, we can only analyse post-intervention data; we do this using OLS regressions (Methods) and assess the robustness of our results using a series of sensitivity analyses (Methods and Supplementary Information 5–8).

To shed light on the mechanisms through which village participation in FLMMA potentially generates impacts, we quantify intermediate outcomes on the causal pathway between the FLMMA intervention and the final outcomes[34] using structural equation modelling (SEM; Methods and Supplementary Information 3). The mechanisms examined here (Fig. 1b) represent the means by which the FLMMA partners and Secretariat support local communities in achieving their desired objectives (Methods), and they include: participation in decision-making, enhanced marine resource knowledge, management of customary fishing grounds (specifically, implementation by villagers of the basic tools needed for effective management, Extended Data Table 1) and external financial and/or infrastructure support[9,35,36].

Through these mechanisms, which are grounded in the theory of collective action and common-pool resource management[9,35,36], partners and communities aim to strengthen traditional systems of

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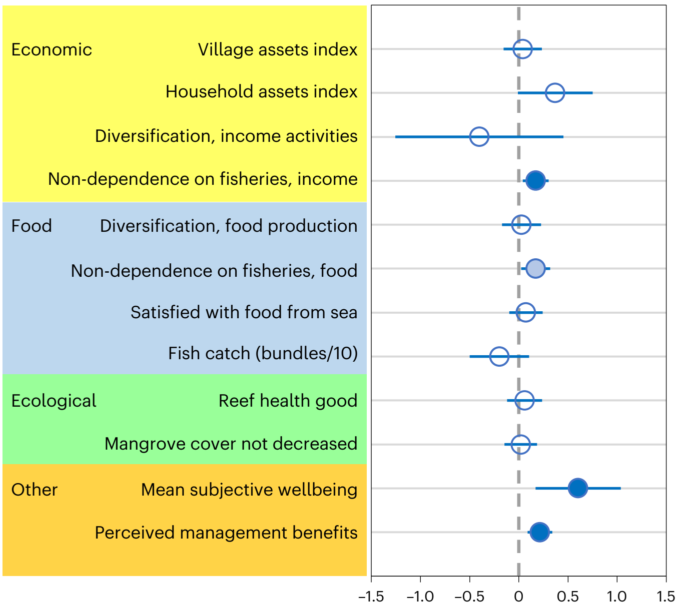

Fig. 2 | Estimates of the impact of FLMMA membership on key outcomes. Impacts are presented as mean values ± 90% confidence intervals. Colour coding is as follows: yellow, economic wellbeing outcomes; blue, food security; green, perceived ecological outcomes; orange, other (subjective wellbeing and perceived benefits of management). Extended Data Table 1 describes individual indicators; Supplementary Information 1 describes how they were operationalized. Sample size in all models is $n = 146$, except for 'satisfied with food from sea' ($n = 145$) and fish catch ($n = 131$) due to non-responses, and reef health ($n = 128$) and mangrove cover ($n = 132$) due to absence of reefs and/or mangroves in some locations. Filled circles (dark blue) indicate that impact as estimated using OLS regressions is significant at $P < 0.05$, and light-blue filled circles indicate $P < 0.1$ (two-sided tests).

sustainable fisheries management, which have been eroded due to colonization and globalization pressures[27], while integrating them with modern fisheries best practices. Broadly, the expectation is that greater participation in decision-making and increased marine resource knowledge—combined with guidance regarding management tools—will lead to more informed and locally appropriate management, which will lead to improved ecological conditions and increased fish catch, which in turn may enhance economic wellbeing and livelihoods, food security and subjective wellbeing. Participation may also directly influence subjective wellbeing. As for financial and/or infrastructure support, this is expected to improve a community's ability to manage its resources, giving rise to other positive impacts (for details about how these mechanisms are expected to lead to the final outcomes examined here, see Methods; Supplementary Information 2 explains how the mechanisms were operationalized). This analysis seeks to identify whether these mechanisms deliver the final outcomes outlined above.

Impacts of LMMAs on final outcomes

Our analysis shows that membership of the FLMMA network has led to impact for 3 of the 12 final outcomes considered here (Fig. 2). Specifically, we find a small but statistically significant impact of FLMMA on mean subjective wellbeing[37] ($P = 0.024$), with the key social groups in FLMMA villages reporting on average that their subjective wellbeing is 0.6 points greater (on a scale of 0–10) than the mean subjective wellbeing of those same social groups in non-FLMMA villages. Results also show a positive influence of FLMMA membership on the perceived benefits from management of the customary fishing grounds. For this question, community leaders were asked to indicate whether their community had experienced improvements in five social and livelihood outcomes (outlined in Extended Data Table 1). Perceived benefits are modelled as a proportion (out of five benefits). Results show that participation in FLMMA is associated with a 22% increase in the proportion of benefits selected by key informants ($P = 0.006$), equivalent to one extra benefit.

We also find that FLMMA villages are 17% more likely to depend on non-fisheries activities for income ($P = 0.033$); there is also moderate evidence of greater dependence on non-fisheries sources for food (17% more likely, $P = 0.056$). This however is not accompanied by increased diversity of income or food-generating activities, suggesting that decreased fisheries dependence is not due to the development of new livelihoods, but to an increased dependence on other pre-existing activities (Supplementary Information 10 and Supplementary Fig. 13). We assessed whether this result is due to reverse causality, whereby villages that depend less on fisheries are more likely to sign up to the network, but statistical testing suggests this is not the case (Methods and Supplementary Information 6).

Neither village infrastructure, household assets, income diversification, food diversification, satisfaction with food from the sea, fish catch, nor perceived ecological health of the reef are influenced by FLMMA membership.

Examining expected mechanisms to impact

Here we decompose the causal pathway from FLMMA to each final outcome (as shown in Fig. 1a) into the various hypothesized mechanisms (participation in decision-making, perceived marine resource knowledge, management of fishing grounds, and financial and/or infrastructure support) (Fig. 1b). This analysis may allow us to elucidate where the process is breaking down between FLMMA and the final outcomes. For example, does the FLMMA intervention fail to activate the hypothesized mechanisms (for example, management)? Or are the mechanisms (for example, management) failing to lead to final outcomes (for example, increased fish catch)? Or are some mechanisms counteracting each other, so that their effects cancel out?

Our findings (Extended Data Fig. 1) show that FLMMA membership leads to positive direct, or indirect, impacts on all the mechanisms, yet these lead to few final outcomes. There is no evidence of mechanisms cancelling each other out, which would be shown if coefficients for any two intermediate outcomes had similar magnitudes but opposite signs. Taken together, these results suggest that the process between FLMMA and the final outcomes breaks down on the causal pathway between the intermediate and final outcomes.

Only four of the final outcomes evaluated in this study were impacted by at least one mechanism. Figure 3 shows results in graphical form for this subset of four final outcomes (for the full set of SEM results for all final outcomes, see Extended Data Fig. 1).

Focusing firstly on the effects of FLMMA on the mechanisms (indicated by the black arrows in Fig. 3), we find that FLMMA membership directly increases average participation in decision-making (increase of 0.43 on a scale of 1 to 5 where 1 represents no participation and 5 represents full participation, $P = 0.004$) and perceived marine resource knowledge (increase of 0.28 on a scale of 1 to 5, where 1 represents not at all knowledgeable and 5 represents very knowledgeable about factors influencing reef health, fisheries diversity and fisheries quantity, $P = 0.001$).). Notably, perceived knowledge is not affected by participation in decision-making ($P = 0.591$). This may be because knowledge is shared informally throughout the community by those who participate in decision-making; alternatively, perceived knowledge gains may arise from other experiences associated with FLMMA membership that are unrelated to participation in decision-making (for example, attendance at workshops).

FLMMA also directly increases the likelihood that a village receives financial and/or infrastructure support (increase of 23%, $P = 0.013$); this support in turn increases the likelihood (by 14.7%, $P = 0.004$) that villages have implemented the basic tools for management of the customary fishing grounds. Combining these results (Methods), we

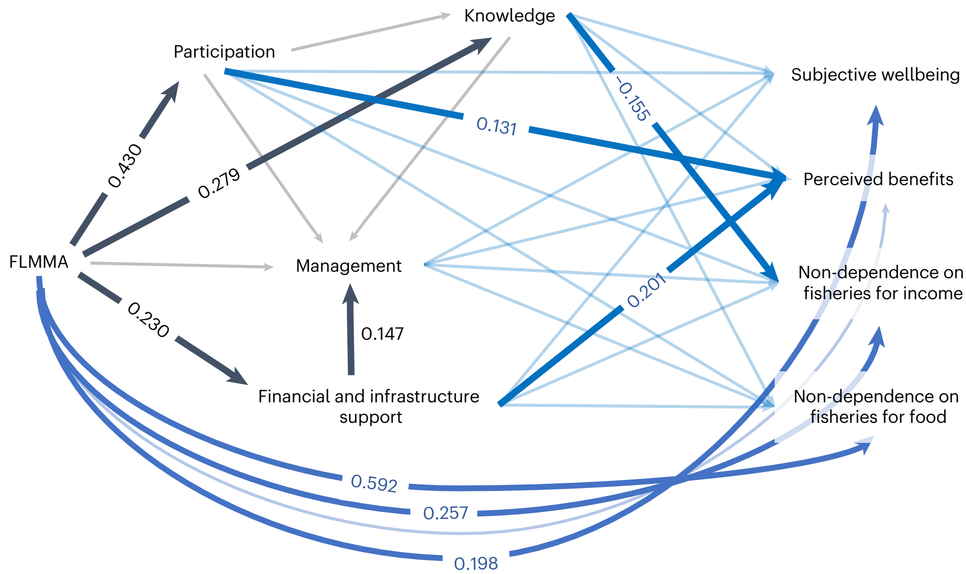

Fig. 3 | Effects of FLMMA via mechanisms on subset of final outcomes found to be influenced by at least one mechanism, including the direct effect from FLMMA. Path coefficients (showing direct effects) shown alongside respective path; black arrows and coefficients are constant across all SEM models irrespective of final outcome. Blue arrows and coefficients vary according to the final outcome being modelled; bolded arrows and coefficients denote significant paths ($P < 0.05$); transparent arrows denote non-significant paths ($P > 0.05$) (two-sided tests). Goodness-of-fit tests for combined SEM (all four outcomes modelled simultaneously): coefficient of determination (CD) of 0.752 (indicating the fraction of variation (variance) explained by model, and standardized root mean square residual (SRMR) of 0.025 (describing the standardized difference between the observed correlation and the predicted correlation, with values <0.08 indicating a good fit). For alternative presentation of results as separate SEM models (coefficients and standard errors are the same), see Supplementary Fig. 14 .

estimate that FLMMA membership indirectly increases management likelihood by 3.4% ($P = 0.067$) via the financial support mechanism.

Notably, FLMMA does not have a direct effect on management, only an indirect effect via financial and/or infrastructure support. However, if we account for all direct and indirect effects of FLMMA on management (that is, via all mechanisms), we find that FLMMA villages are 18.1% more likely ($P = 0.011$) to have in place the basic tools for managing their fishing grounds. Thus, the sum total of these various weak direct and indirect effects leads to a significantly positive effect overall on management likelihood.

These mechanisms, however, translate to impact for only a few final outcomes (shown in Fig. 3). Participation and financial/infrastructure support both increase perceived benefits from management but have no direct effects on other final outcomes. Management has no effect on any of the outcomes—although there is weak evidence of negative effects (household assets and satisfaction with food) (Extended Data Fig. 1).

As for perceived marine resource knowledge, we find (Fig. 3) that villages in which people consider themselves more knowledgeable about marine resources are more dependent on fisheries for income (shown as a negative effect of knowledge on 'non-dependence on fisheries'). If this relationship is indeed causal, it implies that increased knowledge (or perceptions thereof) bolsters fisheries dependence; for example, knowledge about the factors affecting fisheries abundance and diversity may reduce uncertainty about harvests, allow for more targeted efforts and hence moderate the perceived need to shift to non-fishing activities. On the other hand, this relationship may reflect reverse causality, whereby fisheries dependence affects perceived knowledge; however, we are unable to statistically test this (for details, see Methods and Supplementary Information 5). This result highlights the potentially complex role of knowledge in determining FLMMA impacts, and the need to consider possibly unexpected effects and interactions of knowledge with other outcomes, such as fisheries dependence.

The causal pathway with the greatest number of direct effects is the unmediated path leading from FLMMA directly to the final outcomes (Fig. 3). For some final outcomes, such as subjective wellbeing, this direct effect may reflect an intrinsic 'feelgood' factor associated with being part of the FLMMA network. However, this result could also indicate the presence of other mechanisms not considered in this study (Methods). For example, FLMMA membership may provide connections to non-FLMMA organizations and agencies, which could increase access to resources; it may also increase access to alternative livelihood support, which could explain the effect on fisheries dependence. We also acknowledge the possibility that key informants in FLMMA villages were providing socially desirable responses, although data collection was designed to minimize this (Supplementary Information 1). Furthermore, if social desirability explains the results, we would expect similar positive results for other outcomes that could be construed as socially desirable (for example, management or household assets).

Operationalizing mechanisms differently

Here we examine the sensitivity of our results to how we operationalized the mechanisms, focusing on participation in decision-making, perceived marine resource knowledge and management of the customary fishing grounds. We note that financial and/or infrastructure support was elicited and operationalized as a binary variable, so there is only one way we could operationalize it. Our analysis suggests that results are qualitatively similar across different operationalizations of the management and knowledge mechanisms (Supplementary Information 8). How *participation* is operationalized, however, can affect the estimated final outcomes.

Our main indicator of participation represents an average (on a scale of 1–5, where 1 represents no participation/no meetings, 2 represents a little participation, 3 represents moderate participation, 4 represents a lot of participation and 5 represents full participation) over all social groups in a village; given the diversity of approaches used and target groups for participation interventions in FLMMA villages (Methods), we chose this measure of participation as it remains agnostic to how participation is operationalized in practice. However, by representing this mechanism in terms of participation levels of individual social groups—rather than in terms of average participation over all social groups—we find that FLMMA membership significantly increases leaders' participation levels but not those of other social groups. Yet participation of women in decision-making has positive effects on household wealth, food security and fish catch in communities regardless of FLMMA membership (Extended Data Fig. 2). It also has a positive effect on dependence on fisheries for food. We observe no such effects if participation is operationalized in terms of leader or fisher participation levels, or if it is measured in terms of a minimum level of participation across all social groups (Supplementary Figs. 3, 4 and 6). Although villages were not selected to control for factors that might confound the effect of women's participation on these outcomes, statistical tests indicate that these relationships are robust to unobservable confounders, and we find no evidence of endogeneity (Supplementary Information 9), which suggests that these findings approximate causality. These results provide preliminary insights into how participation interventions may be designed and implemented so as to generate social and livelihood benefits.

Discussion

Our study shows that community-based approaches can improve the conditions needed for effective governance of natural resources. Focusing on the FLMMA network, we find higher levels of participation in decision-making around the customary fishing grounds, increased perceived marine resource knowledge, more financial and/or infrastructure support, and an increased likelihood that basic management tools are present in FLMMA villages, compared with non-FLMMA villages. Yet we also find that these mechanisms are not 'working' at delivering the desired social, economic or (perceived) ecological health outcomes. Although outcomes from any policy or intervention may manifest over longer periods of time[11,38], our study finds little evidence of impact 10–15 years after implementation, which is arguably enough to generate impact.

Despite no evidence of economic, livelihood or perceived ecological impacts (with the exception of dependence on fisheries, see below), we found higher levels of subjective wellbeing and more reported benefits from management in FLMMA villages. This echoes findings in Mansuri and Rao[39], who report higher levels of satisfaction among participants of community-based projects around the world, independent of outcomes. Community-based initiatives may thus have intrinsic value to villagers, which could be associated with increased participation and empowerment[40,41], and/or being part of a collective that provides linkages to external agencies and services[42]. This is an important outcome that is likely to ensure the longevity of participation in CBNRM initiatives such as FLMMA.

Nonetheless, ecological and livelihood benefits remain a critical aim for FLMMA as well as other CBNRM initiatives. The only livelihood-related factor shown to be affected by FLMMA is fisheries dependence, with FLMMA membership leading to less dependence on fisheries for income (with statistical tests refuting the possibility of reverse causality). This effect is not mediated by any of the proposed mechanisms and is not accompanied by increased income diversification. Perceived marine resource knowledge does have an effect, although it is opposite in direction (that is, it is associated with increased fisheries dependence); whether this effect is causal, as proposed by our model, or suggestive of reverse or simultaneous causality, could not be ascertained due to insufficient information for statistical testing (Supplementary Information 5), and remains an area for in-depth further research. Regardless of the role of perceived knowledge in our causal model, there remains a substantial negative effect of FLMMA on fisheries dependence that is not mediated by any of the considered mechanisms. This result highlights the importance of quantifying the expected mechanisms underlying CBNRM interventions, as this can reveal gaps in our causal models and pave the way for further research to uncover mechanisms to change.

More detailed examination of the mechanisms through which FLMMA partners support villages (Supplementary Information 8) provides key insights into why FLMMA has had only modest effects on final outcomes, as measured here. Specifically, we found that FLMMA membership improves leaders' participation levels, and yet it is women's participation—which is not affected by FLMMA—that has positive effects on a range of outcomes, including food security and household wealth (Extended Data Fig. 2). In Fiji, women fishers play a critical role in food security and household income contributions[43,44], which would explain why their participation leads to improvements in these specific outcomes. Other studies have highlighted how women's participation can improve household-level outcomes across a range of settings[45–47]. Given that women's fishing activities (for example, gleaning) typically differ from men's (for example, offshore fishing)[43,48], their participation in fisheries decision-making is critical to ensure management also benefits the fisheries that they participate in. Although more research is needed on participation in CBNRM, including applying a gender lens to understand outcomes, these findings broadly suggest that different social groups may be better able and/or motivated to deliver different outcomes. This highlights the importance of extending participation in decision-making to all social groups, and/or targeting it as needed[49].

As for management, we found this mechanism had no effect on our measured final outcomes, regardless of how the indicator was operationalized (Supplementary Information 8). We might expect that having the basic tools to manage a fishing ground (that is, the presence of rules, monitoring, enforcement and penalties, Extended Data Table 1) would benefit livelihoods via improved fisheries and marine resources; however, there is no evidence that this is the case. Recent studies about marine management in Fiji have linked management performance to factors such as appropriateness of the rules[30,50], management capacity shortfalls[51] and biophysical and wider ecosystem context[52]. Identifying how and why management leads to impact (or not) would ideally require analysis of more elaborate causal pathways capturing detailed ecological conditions with controls for biophysical context, better ecological and fisheries data based on ecological assessments rather than perceptions, more detailed measures of management, compliance and user behaviour, and data on implementation of national policies governing natural resource management. Ideally these data would be collected at baseline and at regular intervals, allowing researchers and practitioners to identify where causal processes are stalling or breaking down. This information would strengthen the causal models explaining change and inform the design and implementation of effective management interventions[18,31].

Limitations

Although the results from this study may provide a better understanding of community-based management in Fiji and other Pacific Island countries, these findings may not be generalizable to other countries or contexts. Property rights for Indigenous populations are relatively well developed in Fiji and other Pacific Island countries and territories[27], but this is not necessarily true in other countries with CBNRM initiatives[53,54]. This is critical as the underlying mechanisms determining impact will probably vary depending on communities' resource management rights. As noted in ref. 20 (p. 4336), to develop a comprehensive understanding of the mechanisms driving conservation and resource management, we need to build an evidence base on a 'policy-by-policy and country-by-country (or region-by-region) basis'. This study contributes to this endeavour.

Our conclusions are also tempered by the lack of baseline and/or longitudinal data on outcomes or mechanisms. Although the 'single differences' approach used here can generate robust causal results[33], this hinges on the assumption that FLMMA and non-FLMMA villages would have evolved in parallel in the absence of treatment, and that there is no reverse or simultaneous causality undermining the results. Although statistical tests (Supplementary Information 5 and 6) show no evidence of reverse causality or the presence of unobservable confounders—suggesting that our findings approximate causality—ex post statistical tests are no substitute for quality baseline and monitoring social and ecological data, which would allow for more robust causal inference. Conservation and natural resource management efforts would greatly benefit from concerted data collection efforts in this regard.

We also emphasize that the wide variety of organizations and approaches that operate under the umbrella of the FLMMA network, and the range of resources invested across sites (an estimated 30-fold range in yearly investments[55]), invariably affects the type, duration and intensity of support provided. Additionally, the objectives of partners may differ from those of communities, and the degree of match may affect the success of the collaborations. Depending on which factors are more likely to influence outcomes, there may be a need to specifically identify the investments and specific interventions used in conjunction with a more elaborate causal model (theory of change) in future studies.

Despite these limitations, our study demonstrates the importance of identifying whether environmental and/or social interventions are in fact 'working', and whether the components of these interventions are effective at delivering desired outcomes. This is particularly critical in light of the need to cost-effectively increase the scale and effectiveness of CBNRM[49]. Our study adds to the growing number of studies using counterfactual methods to elucidate impact of community-based conservation and natural resource management approaches[13–17]. With this growing evidence base, communities and supporting partners will be increasingly able to co-design and co-implement effective conservation and natural resource management policies. Our findings suggest that FLMMA practitioners and communities need to carefully evaluate the mechanisms and tools that are expected to generate benefits to communities; one recommendation is to find ways to encourage broader participation in fisheries decision-making, given that different social groups may be better able and/or motivated to deliver different outcomes. These are first steps towards more effective community-based management of marine resources; we anticipate that future research building on these findings will add to our understanding of how CBNRM initiatives can improve outcomes for people and the rest of nature.

Methods

LMMAs in Fiji

The FLMMA network, established in 2001, spans over 350 communities across 12 provinces (FLMMA 2020 database). Fisheries management efforts among member villages are applied to the *iqoliqoli*, which are coastal waters that villagers have customary rights to fish from. These *iqoliqoli* extend from the shore to the seaward limit of the reef, and are demarcated by the boundaries of the *vanua*[56], which comprises the land, coastal waters and Indigenous people living on the land, all of which are treated as a single, indivisible unit[57]. Inherent in the *vanua* concept is stewardship for the environment[58] and maintaining this for future generations[59]. A key tradition that helped form the basis for the LMMA approach is the funeral ritual associated with the death of a high chief. This centuries-old tradition involves closing off small areas of reef and/or river for a hundred nights following the burial of the high chief to allow fish populations to recover; this is known as a 'tabu' area[60,61]. LMMAs today integrate such traditional practices and Indigenous fisheries knowledge with modern fisheries best practices (https://lmmanetwork.org/our-work-building-on-traditional-practices/).

Sample selection

We selected study villages from a list of 581 coastal villages in Fiji (excluding Lau and Rotuma) located within 1 km of the water for which we had spatial data (source: Ministry of Lands & Resources). Our identification of 'intervention' villages was based on the list of villages in the FLMMA 2019 database. For a village to be listed in the database, the following criteria were applied, as determined in the FLMMA constitution[29]: (1) the village must have reached out to the FLMMA network and formally requested support, (2) the application must be endorsed by the village council and signed by the head of village, (3) there is an assessment confirming the need for support. FLMMA study sites are thus defined as villages in the FLMMA database, while non-FLMMA sites are defined as villages that are not in the database and that have never been listed there. Given that villages join the FLMMA network in a continuous manner over time, our sampling frame included only FLMMA villages established ~15 years ago (between 2004 and 2007; $n = 94$), and ~10 years ago (between 2009 and 2012; $n = 88$). This selection approach allowed us to have a sufficiently large sampling frame in which impacts of FLMMA membership have had time to manifest[38] while moderating variability due to the year of adoption, or duration of the intervention. We constrained our sampling frame to account for spillover effects, shared customary fishing grounds and removed non-FLMMA villages that had other marine management projects. Details about the sampling strategy are provided in Supplementary Information 1.

We used one-to-one propensity score matching without replacement to select non-FLMMA villages so that they resembled FLMMA villages at baseline with regard to covariates expected to influence both LMMA adoption and impacts. The covariates used in matching were: distance to nearest road, distance to nearest market, distance to nearest previously established LMMA, area of customary fishing ground, coral reef cover and number of other villages sharing the fishing ground. This resulted in a sample of 152 villages, of which half were FLMMA members (for details, see Supplementary Information 1).

Data collection

We collected data between October 2019 and March 2020 through interviews with four groups of key informants—village leaders, women, fishers and the youth (defined as people between the ages of 18 and 35) (Supplementary Information 1). With reference to the village leader group, we note that leadership in iTaukei (native or Indigenous Fijian) villages is predominantly held by men, although it is acceptable for women to be chiefs. Three of the study villages included a woman in the village leader group. In advance of the interviews, requests were sent to the head of the group (if relevant) along with other members of the group prior to the visit, to ensure that people were available for the interview.

Participants were selected through consultation with the village chief and other senior leaders in the community, with inputs from other community representatives present during the traditional *sevusevu* ceremony. The *sevusevu* is the equivalent of a free, prior and informed process that is conducted in Fiji by any researcher (local or foreign) wishing to interview people in a village. Consent was obtained from the village chief before any interviews were conducted, followed by individual consent from key informants. Data collection was designed to minimize social desirability response bias among respondents in FLMMA villages (Supplementary Information 1). The teams spent an average of 60 min on interviews, although leaders' interviews averaged 75 min. Due to unforeseen events during fieldwork, our final sample includes data from 134 matched village pairs, and data from 12 additional unmatched villages ($n = 11$ FLMMAs, and $n = 1$ non-FLMMA). However, as covariate balance for the final sample (Supplementary Table 5) compares favourably to that of the matched sample (Supplementary Table 3), we opt to use all the data for analysis. The final sample size is 146 villages (for details of sampling and map of study sites, see Supplementary Information 2).

Selection of final outcomes

The aim of LMMAs is to enhance coastal villages' ability to manage and sustainably use their marine resources. However, communities have varied motivations for establishing and maintaining LMMAs[30]; hence, multiple indicators are needed to measure impact. We therefore focused our analysis on the broad outcomes identified as most desirable by FLMMA villagers (recorded in ref. 30 and ref. 27), which include: improved economic wellbeing and livelihoods, and food security. The indicators used to measure these broad outcomes are listed in Extended Data Table 1. Indicators were selected using expert knowledge from Fijian team members who have worked with coastal villages in Fiji for 20+ years, and who have extensive experience collecting socio-economic and ecological data, while considering published research from Fiji, particularly on LMMAs[50,59,62], as well as from the wider marine conservation literature[13,31], and a social–ecological monitoring handbook for coastal fisheries[63].

The final list of indicators includes two measures of wealth (village-level and household-level assets), two indicators of livelihood security (income diversification and dependence on fisheries for income), a measure of self-reported satisfaction with food from the sea and two measures of food security (diversification of food production and dependence on fisheries for food). Political empowerment is also listed as a desirable outcome by villagers[27,30], although we include this as an intermediate outcome, as it is expected to mediate other outcomes. We also considered ecological outcomes, which are important for marine CBNRM generally[31,64]. Ideally, we would have directly measured ecological health using indicators such as fish biomass, coral algae cover and mangrove canopy cover; however, due to limited resources we had to rely on perceptions from fishers (about coral health and change in mangrove cover over time). We also elicited subjective wellbeing, which is increasingly recognized to contribute to quality of life beyond material factors[65], and villagers' perceived benefits from management of the customary fishing grounds. Supplementary Information 1 details how indicators were operationalized. All outcomes analysed for this study are based on quantitative data obtained during key informant interviews.

Selection of mechanisms

The mechanisms examined in this study were identified through discussions with members of the FLMMA secretariat, and partner organizations working with villages in Fiji. These mechanisms (Fig. 1b) are hypothesized to mediate the impact of FLMMA membership on the final outcomes. We quantify these mechanisms by estimating relevant intermediate outcomes that are hypothesized to lie on the causal pathway between the LMMA intervention and the final outcomes[34].

One of the most important mechanisms through which FLMMA partners aim to support communities is through increased villager *participation* in decision-making about marine management[25]. Despite formal recognition of customary rights to use and manage coastal resources, globalization pressures combined with a post-colonial top-down approach to planning have reduced engagement in traditional systems of sustainable marine management[27]. By encouraging increased participation of local communities in managing their own resources (bearing in mind that participation levels will vary depending on the approaches used by different partners in the villages they work with[66,67]), the expectation is that rules implemented in the customary fishing grounds will be culturally and locally appropriate, and hence more likely to be complied with, in turn leading to improvements in ecological conditions (reef health and mangrove cover) and increased fish catch[50]. These expectations are aligned with the wider literature that finds that participation promotes improved management, because local knowledge can improve complex management decisions[68], and involvement in management decisions can increase support for and compliance with the rules[35,36,69]. We also anticipate that greater participation may increase subjective wellbeing (for example, refs. 70,71). Although we do not expect participation to directly influence economic wellbeing or food security, these could be indirectly influenced by participation through improved increased fish catch. Our analysis of these causal pathways (from FLMMA through participation to economic wellbeing or food security) are exploratory.

Another mechanism through which FLMMA aims to generate social and ecological benefits, is improved management of marine resources. Although customary systems of resource management have always existed, these were eroded during colonization in the twentieth century[27,72]. Thus, technical skills and training are provided by FLMMA partners via on-site workshops and meetings to help strengthen traditional management approaches, and to support implementation of science-based tools[29]. FLMMA organizations and villages are encouraged to share knowledge generated through their experiences with different fisheries management practices[29] with the expectation that villages will gain insights about best practices around fisheries management.

The effect of this mechanism could go two ways: on the one hand, the implementation of rules, monitoring, penalties and enforcement (Extended Data Table 1) may increase conflicts and non-compliance if considered unfair to fishers, which could negatively impact ecological and social outcomes (for example, food security). Alternatively, management may improve fish catch and ecological conditions if the rules are complied with, thus increasing food security. The direction of influence remains an empirical question. We also expect management to indirectly impact economic wellbeing via changes in fish catch. Analyses of all other causal pathways are exploratory, as we have no prior expectations in this regard.

Marine resource knowledge is another key mechanism that is expected to improve livelihoods and ecological outcomes. By providing training and sharing knowledge about the factors influencing local marine resource health, FLMMA organizations aim to counteract the loss of traditional marine resource knowledge that has occurred across Fiji[27]—and this is expected to lead to more informed decisions about management, which may translate to improved ecological conditions[73]. In this study, we use perceived marine resource knowledge as our knowledge indicator (discussed in more detail in Supplementary Information 1).

Increased marine resource knowledge (or perceptions thereof) may also influence livelihood choices, although the direction of influence may vary: for example, increased perceived knowledge about the link between fishing effort and fisheries health may encourage fishers to shift their efforts to other livelihood activities where possible, thus decreasing their fisheries dependence; alternatively, increased awareness about factors influencing fisheries abundance may encourage increased fishing effort in (say) certain locations or at certain times of year. Although we do not expect knowledge to directly impact economic wellbeing (Extended Data Table 1), it may have an indirect effect through adjustments in fishing behaviour that influence fish catch. These are exploratory questions.

We also examine the impact of financial and/or infrastructure inputs from external partners to FLMMA villages. These key inputs are provided in variable amounts by different partners to different villages[55], and are expected to influence a community's ability to manage its resources, which may enhance ecological outcomes, as well as (indirectly, via improved fish catch) economic and subjective wellbeing.

Causal model

The hypothesized causal pathways through which FLMMA membership is expected to improve final outcomes are shown in Fig. 1b. Arrows linking variables in the model indicate direct causal effects. Indirect effects (for example, from LMMA through participation to final outcomes) are calculated by multiplying coefficients on the pathways (for example, from LMMA to participation, and from participation to final outcomes). The sum of all direct and indirect effects equals the overall average treatment effect, that is, the single arrow from FLMMA to the final outcomes in Fig. 1a.

Any effect not caused by these hypothesized mechanisms is captured via the arrow from FLMMA to final outcomes. This might include effects due to unaccounted-for mechanisms, or it might capture an 'intrinsic' sense of belonging associated with participation in the FLMMA network, which in turn may impact the final outcomes. Our design does not allow us to disentangle these intrinsic effects from the effects of unaccounted-for mechanisms; we can identify only whether there is an average FLMMA treatment effect that is net of other effects.

We acknowledge that these four mechanisms may not represent all possible mechanisms, and that the causal model may not represent the full complexity of the processes by which FLMMA village membership leads to different outcomes. As noted by Ferraro and Hanauer[74], the degree of elaboration of causal pathways depends on how well developed the theory is that guides the specification, the goals of the study, and the data available. In the present study, we are constrained by the amount of data available, which limits our ability to model multiple intermediate steps along the main pathways. Additionally, there is scarce robust evidence about the causal mechanisms through which CBNRM initiatives lead to impacts. Hence, we focus on broad mechanisms, and anticipate that future studies will build on this by investigating more elaborate processes within these broad mechanisms.

Finally, we note that, while LMMAs share some common principles, there is diversity in how these principles are operationalized across Fiji[30,75]. The FLMMA 'treatment' thus does not consist of a standardized intervention with clearly defined and implemented components, but may be considered a 'complex intervention'[76]. It is suggested[76,77] that evaluations of complex interventions should avoid narrow definitions of the intervention or its components and should standardize on the 'function' of the intervention; multiple methods to address questions from different angles are also advised. This study is designed with these considerations in mind.

Statistical analysis

We combine matching with regressions (in which we control for treatment status, covariates used in matching and other controls) to obtain estimates of impact on final outcomes. Linear regressions were used for all models, irrespective of whether the outcome measure is binary, ordinal, count or continuous (Supplementary Information 3). We use the reg command in Stata 17.0 (ref. 78) to conduct ordinary least squares (OLS) regressions, with clustering by *iqoliqoli* (customary fishing ground) to account for potential correlations in outcomes between villages sharing *iqoliqolis*. We note that, when multiple villages share *iqoliqolis*, they typically fish and extract resources from the area in front of the village, and do not fish or glean in front of other villages. They also usually make management decisions independently from each other. Clustering the standard errors allows us to control for correlations between the characteristics of villages sharing an *iqoliqoli*. To verify whether we are justified in using linear regressions on categorical variables, we compare results from various models; we confirm that OLS regressions produce unbiased estimates of impact (Supplementary Information 4 and Supplementary Table 6).

SEM was used to identify the role of different mechanisms in mediating the influence of FLMMA on final outcomes of interest. To do this, we used the sem command in Stata 17.0 on all 12 final outcomes examined in this study, with the same set of potential confounders used in the OLS regressions controlled for in all paths of the models, and with clustering by *iqoliqoli*. Goodness-of-fit tests indicate a good fit overall for all models (Extended Data Fig. 1).

Although multiple analyses were performed on this dataset, we do not make post hoc adjustments for multiple comparisons, as per recommendations in refs. 79–82. The theoretical basis for such adjustments is that 'chance' serves as the first-order explanation for observed phenomena—known as the 'universal null hypothesis'[80]. Since our analysis is based on actual observations and not randomly distributed numbers, non-adjustment facilitates correct interpretation of results. Furthermore, given that we are examining multiple individual outcomes—and not conducting multiple tests of one joint outcome[82]—it makes sense to evaluate the results of individual tests one-by-one without adjustment while addressing the internal consistency of results[83]. Each individual analysis still retains a probability of Type I error of $P < 0.05$. While post hoc adjustments based on the number of tests may reduce Type I errors, they also increase the likelihood of Type II errors, potentially resulting in important findings being deemed non-significant. As many of our analyses are exploratory (for example, influence of FLMMA on subjective wellbeing), the risk of missing these findings is considered non-negligible. We therefore present unadjusted results and acknowledge the risk that some findings may be false positives.

Sensitivity analyses and alternative explanations

We examine the sensitivity of our results to different ways of operationalizing the indicators and conducting the analysis. Firstly, we explore whether the impacts of FLMMA membership on the final outcomes can be considered causal, or potentially due to reverse (or simultaneous) causality. To do this we assess the likelihood that FLMMA membership is endogenous (that is, explained by other variables in the model), as this may be indicative of reverse causality. We find no evidence of endogeneity (Supplementary Information 5) for any of the final outcomes (including dependence on fisheries, discussed above), suggesting that the direction of causality goes from FLMMA to final outcomes, and not the other way round (that is, the outcomes did not cause villages to join FLMMA).

Results are less clear with respect to the impact of FLMMA on the hypothesized mechanisms; although we find no evidence of reverse or simultaneous causality for participation, results are not conclusive for perceived marine resource knowledge as we had insufficient information to conduct reliable tests for this variable (Supplementary Information 5). As for management, we could not evaluate endogeneity with respect to this mechanism, so the extent to which FLMMA membership is influenced by management (indicating reverse causality) cannot be tested. If there were a reverse causal relationship between FLMMA and knowledge or management (and we emphasize that we have no evidence supporting or refuting this), any estimated effect of FLMMA on these mechanisms would be smaller than estimated. If, however, knowledge or management influenced FLMMA membership and the final outcomes, this would imply the presence of unaccounted-for confounding that could affect our results. However, tests (reported below) show no evidence of unobservable confounding. Crucially, given that FLMMA partners aim to support increased knowledge about marine resource management and to encourage adoption of the various management tools examined here, we consider it unlikely that the influence of FLMMA on perceived knowledge and management is due to reverse causality. We do not evaluate endogeneity for financial and/or infrastructure support, as this indicator refers explicitly to support provided after a village joined the FLMMA network, removing any potential for reverse causality.

We also examine sensitivity to unobservable confounding, using a method proposed by Oster[84] that produces an estimate of the degree of selection on unobservables (omitted or missing variables) compared with observable variables that would be needed to confound the effect of interest (that is, FLMMA impact). Focusing only on those final outcomes that were significant in the OLS regressions (Fig. 2) and all intermediate outcomes (mechanisms), we show that results are robust to the presence of unobservable influences (Supplementary Information 6).

Turning to specific results of interest, we statistically assess whether the positive relationship between perceived knowledge and dependence on fisheries for income (Fig. 3) is causal. We find no evidence of unobservable confounding suggesting that the effect is causal; however, we were unable to directly test for reverse or simultaneous causality, so we cannot know whether knowledge influences dependence on fisheries for income, or the other way around (Supplementary Information 6).

Additional sensitivity analyses confirm that estimated impacts are robust to different buffer zone specifications, that is, the minimum distance between villages (Supplementary Information 8). Finally, we ran the same analysis but differentiating between older LMMAs (those established ~15 years ago) and younger LMMAs (established ~10 years ago); results show that these perform similarly to each other (Supplementary Information 10 and Supplementary Fig. 15).

Ethical considerations

This research was approved by the Middlesex University Ethical Review Board (application number 8030) on 17 July 2019. Consent was obtained from the village chief before any interviews were conducted, followed by individual consent from key informants.

Reporting summary

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

Data availability

Summary data that support the findings of this study are available within the paper and Supplementary Information. FLMMA member village data are available upon request from the FLMMA Secretariat (email contact: info@lmmanetwork.org). Covariate data used for matching were provided by the Ministry of Lands and Mineral Resources and Fiji Roads Authority, with the exception of coral cover data, which are publicly available from the Millennium Coral Reef Mapping Project (available at https://oceancolor.gsfc.nasa.gov/cgi/landsat.pl). Raw data from the interviews are available on request from the corresponding author (T.O.) with reasonable restrictions, as respondents belong to the Indigenous iTaukei group and have additional protections under our ethical review process. Data and code used for the analysis will be made available no more than 2 weeks after the data use agreement has been agreed and signed.

Code availability

Stata code used for analysis in this study is available at the repository in the Open Science Framework (https://osf.io/g94ya/).

References

1. Roe, D. The origins and evolution of the conservation-poverty debate: a review of key literature, events and policy processes. *Oryx* **42**, 491–503 (2008).
2. Cinner, J. E. et al. Comanagement of coral reef social–ecological systems. *Proc. Natl Acad. Sci. USA* **109**, 5219–5222 (2012).
3. Gurney, G. G. et al. Biodiversity needs every tool in the box: use OECMs. *Nature* **595**, 646–649 (2021).
4. Diz, D. et al. Mainstreaming marine biodiversity into the SDGs: the role of other effective area-based conservation measures (SDG 14.5). *Mar. Policy* **93**, 251–261 (2018).
5. Jonas, H. D., Barbuto, V., Jonas, H. C., Kothari, A. & Nelson, F. New steps of change: looking beyond protected areas to consider other effective area-based conservation measures. *PARKS* **20**, 111–128 (2014).
6. Brooks, J., Waylen, K. A. & Mulder, M. B. Assessing community-based conservation projects: a systematic review and multilevel analysis of attitudinal, behavioral, ecological, and economic outcomes. *Environ. Evid.* **2**, 1–34 (2013).
7. Berkes, F. Rethinking community-based conservation. *Conserv. Biol.* **18**, 621–630 (2004).
8. Shackleton, C. M., Willis, T. J., Brown, K. & Polunin, N. V. C. Reflecting on the next generation of models for community-based natural resources management. *Environ. Conserv.* **37**, 1–4 (2010).
9. Nelson, F. & Agrawal, A. Patronage or participation? Community-based natural resource management reform in Sub-Saharan Africa. *Dev. Change* **39**, 557–585 (2008).
10. Blaikie, P. Is small really beautiful? Community-based natural resource management in Malawi and Botswana. *World Dev.* **34**, 1942–1957 (2006).
11. Evans, L., Cherrett, N. & Pemsl, D. Assessing the impact of fisheries co-management interventions in developing countries: a meta-analysis. *J. Environ. Manag.* **92**, 1938–1949 (2011).
12. Galvin, K. A. et al. African community-based conservation: a systematic review of social and ecological outcomes. *Ecol. Soc.* https://doi.org/10.5751/ES-10217-230339 (2018).
13. Gurney, G. G. et al. Poverty and protected areas: an evaluation of a marine integrated conservation and development project in Indonesia. *Glob. Environ. Change* **26**, 98–107 (2014).
14. Rasolofoson, R. A., Ferraro, P. J., Jenkins, C. N. & Jones, J. P. G. Effectiveness of community forest management at reducing deforestation in Madagascar. *Biol. Conserv.* **184**, 271–277 (2015).
15. Keane, A. et al. Impact of Tanzania's wildlife management areas on household wealth. *Nat. Sustain.* **3**, 226–233 (2019).
16. Slough, T. et al. Adoption of community monitoring improves common pool resource management across contexts. *Proc. Natl Acad. Sci. USA* https://doi.org/10.1073/pnas.2015367118 (2021).
17. Coppock, D. L. et al. Community-based rangeland management in Namibia improves resource governance but not environmental and economic outcomes. *Commun. Earth Environ.* **3**, 1–17 (2022).
18. Cheng, S. H. et al. Strengthen causal models for better conservation outcomes for human well-being. *PLoS ONE* **15**, e0230495 (2020).
19. Biggs, D. et al. Developing a theory of change for a community-based response to illegal wildlife trade. *Conserv. Biol.* **31**, 5–12 (2017).
20. Ferraro, P. J. & Hanauer, M. M. Quantifying causal mechanisms to determine how protected areas affect poverty through changes in ecosystem services and infrastructure. *Proc. Natl Acad. Sci. USA* **111**, 4332–4337 (2014).
21. Reimer, M. N. & Haynie, A. C. Mechanisms matter for evaluating the economic impacts of marine reserves. *J. Environ. Econ. Manag.* **88**, 427–446 (2018).
22. Wiik, E. et al. Mechanisms and impacts of an incentive-based conservation program with evidence from a randomized control trial. *Conserv. Biol.* **34**, 1076–1088 (2020).
23. Miteva, D. A., Pattanayak, S. K. & Ferraro, P. J. Evaluation of biodiversity policy instruments: what works and what doesn't?. *Oxf. Rev. Econ. Policy* **28**, 69–92 (2012).
24. Aalbersberg, B., Tawake, A. & Parras, T. Village by village: recovering Fiji's coastal fisheries in *World Resources 2005: The Wealth of the Poor: Managing Ecosystems to Fight Poverty,* 144–151 (World Resources Institute, in collaboration with United Nations Development Programme, United Nations Environment Programme and World Bank, 2005).
25. Govan, H., Aalbersberg, W., Tawake, A. & Parks, J. E. Locally-managed marine areas: a guide to supporting community-based adaptive management (*The Locally-Managed Marine Area Network,* 2008); https://lmmanetwork.org/wp-content/uploads/2021/08/Govan-et-al-2008-LMMA-CBAM-Guide.pdf
26. Parks, J. E. & Salafsky, N. *Fish for the Future? A Collaborative Test of Locally-Managed Marine Areas as a Fisheries Conservation and Resource Management Tool in the Indo-Pacific Region* (World Resources Institute, 2001).
27. Govan, H. et al. *Status and Potential of Locally-Managed Marine Areas in the South Pacific: Meeting Nature Conservation and Sustainable Livelihood Targets through Wide-Spread Implementation of LMMAs* (SPREP/WWF/WorldFish-Reefbase/CRISP, 2009).
28. Govan, H., Tawake, A. & Tabunakawai, K. Community-based marine resource management in the South Pacific. *PARKS* **16**, 63–68 (2006).

29. FLMMA operations guide: the way we work together. *FLMMA* https://www.sprep.org/attachments/pipap/flmma_operations_guide_1.pdf (2011).
30. Jupiter, S. D., Cohen, P. J., Weeks, R., Tawake, A. & Govan, H. Locally-managed marine areas: multiple objectives and diverse strategies. *Pac. Conserv. Biol.* **20**, 165–179 (2014).
31. Mascia, M. B. et al. A novel framework for analyzing conservation impacts: evaluation, theory, and marine protected areas. *Ann. N. Y. Acad. Sci.* **1399**, 93–115 (2017).
32. Wauchope, H. S. et al. Protected areas have a mixed impact on waterbirds, but management helps. *Nature* **605**, 103–107 (2022).
33. Ferraro, P. J. & Miranda, J. J. The performance of non-experimental designs in the evaluation of environmental programs: a design-replication study using a large-scale randomized experiment as a benchmark. *J. Econ. Behav. Organ.* **107**, 344–365 (2014).
34. Imai, K., Keele, L., Tingley, D. & Yamamoto, T. Unpacking the Black Box of Causality: learning about causal mechanisms from experimental and observational studies. *Am. Polit. Sci. Rev.* **105**, 765–789 (2011).
35. Ostrom, E. *Governing the Commons: The Evolution of Institutions for Collective Action*. *Governing the Commons: The Evolution of Institutions for Collective Action* (Cambridge Univ. Press, 1990).
36. Ostrom, E. in *The New Palgrave Dictionary of Economics and the Law* (ed. Newman, P.) 1824–1833 (Springer, 2002).
37. Cantril, H. *The Pattern of Human Concerns* (Rutgers Univ. Press, 1965).
38. Brooks, J. S. Design features and project age contribute to joint success in social, ecological, and economic outcomes of community-based conservation projects. *Conserv. Lett.* https://doi.org/10.1111/conl.12231 (2017).
39. Mansuri, G. & Rao, V. *Localizing Development: Does Participation Work?* (World Bank, 2013).
40. Mangubhai, S., Sykes, H., Manley, M., Vukikomoala, K. & Beattie, M. Contributions of tourism-based Marine Conservation Agreements to natural resource management in Fiji. *Ecol. Econ*. **171**, 106607 (2020).
41. Veitayaki, J. et al. Addressing human factors in fisheries development and regulatory processes in Fiji: the Mositi Vanuaso experience. *Ocean Yearb. Online* **21**, 289–306 (2007).
42. Govan, H. Review of government fisheries resource management effort, Northern Division, Fiji Islands. *Wildlife Conservation Society* https://drive.google.com/file/d/0B0_H-Pi4pRUuNzN2WHFhUzlVTWM/view?resourcekey=0-lIRyriEJ9hebWg3F-Oj87Q (2016).
43. Thomas, A. et al. Why they must be counted: significant contributions of Fijian women fishers to food security and livelihoods. *Ocean Coast Manag.* **205**, 105571 (2021).
44. Syddall, V. M., Fisher, K. & Thrush, S. What does gender have to do with the price of tuna? Social–ecological systems view of women, gender, and governance in Fiji's tuna fishery. *Marit. Stud.* **21**, 447–463 (2022).
45. Agarwal, B. The power of numbers in gender dynamics: illustrations from community forestry groups. *J. Peasant Stud.* **42**, 1–20 (2015).
46. Chattopadhyay, R. & Duflo, E. Women as policy makers: evidence from a randomized policy experiment in India. *Econometrica* **72**, 1409–1443 (2004).
47. Grillos, T. Women's participation in environmental decision-making: quasi-experimental evidence from northern Kenya. *World Dev.* **108**, 115–130 (2018).
48. Kitolelei, S., Breckwoldt, A., Kitolelei, J. & Makhoul, N. Fisherwomen's Indigenous and local knowledge—the hidden gems for the management of marine and freshwater resources in Fiji. *Front. Mar. Sci.* **9**, 2339 (2022).
49. Pacific framework for action on scaling up community-based fisheries management: 2021–2025. *Pacific Community* https://purl.org/spc/digilib/doc/yr5yv (2021).
50. Jupiter, S. D. et al. A social–ecological systems approach to assessing conservation and fisheries outcomes in Fijian locally managed marine areas. *Soc. Nat. Resour.* **30**, 1096–1111 (2017).
51. Gill, D. A. et al. Capacity shortfalls hinder the performance of marine protected areas globally. *Nature* **543**, 665–669 (2017).
52. Fidler, R. Y. et al. The importance of biophysical context in understanding marine protected area outcomes for coral reef fish populations. *Coral Reefs* **40**, 791–805 (2021).
53. Persha, L., Agrawal, A. & Chhatre, A. Social and ecological synergy: local rulemaking, forest livelihoods, and biodiversity conservation. *Science* **331**, 1606–1608 (2011).
54. Rocliffe, S., Peabody, S., Samoilys, M. & Hawkins, J. P. Towards a network of locally managed marine areas (LMMAs) in the Western Indian Ocean. *PLoS ONE* **9**, e103000 (2014).
55. Govan, H., Tawake, A., Korovulavula, I. & Tawakelevu, S. *Summary analysis of site support costs for Fiji Locally Managed Marine Area (FLMMA) - Institute of Applied Sciences (USP) sites*. IAS Technical Report No. 2009/2 (2009); https://www.academia.edu/2230616/Summary_analysis_of_site_support_costs_for_Fiji_Locally_Managed_Marine_Area_FLMMA_Institute_of_Applied_Sciences_USP_sites
56. Veitayaki, J. in *Culture and Sustainable Development in the Pacific* (ed. Hooper, A.) 116–130 (ANU Press, 2000).
57. Ravuvu, A. *Vaka i taukei: the Fijian Way of Life* (Institute of Pacific Studies of the University of the South Pacific, 1983).
58. Yee, M., McNamara, K. E., Piggott-McKellar, A. E. & McMichael, C. The role of Vanua in climate-related voluntary immobility in Fiji. *Front. Clim.* **4**, 237 (2022).
59. O'Garra, T. Bequest values for marine resources: how important for Indigenous communities in less-developed economies? *Environ. Resour. Econ.* **44**, 179–202 (2009).
60. Vave, R. Changing expressions of grieving in Indigenous Fijian funerals – ICH Courier. *ICH Courier Online*, **38**, 18–19 (2019); https://ichcourier.unesco-ichcap.org/changing-expressions-of-grieving-in-indigenous-fijian-funerals/
61. Vave, R. Five culturally protected water body practices in Fiji: current status and contemporarydisplacement challenges. *Ambio* **51**, 1001–1013 (2022).
62. Gurney, G. G. et al. Implementing a social–ecological systems framework for conservation monitoring: lessons from a multi-country coral reef program. *Biol. Conserv.* **240**, 108298 (2019).
63. Gurney, G. G. & Darling, E. S. *A Global Social–Ecological Systems Monitoring Framework for Coastal Fisheries Management. A Practical Monitoring Handbook* (Wildlife Conservation Society, 2017).
64. Brooks, W. R. et al. Social and ecological outcomes of conservation interventions in tropical coastal marine ecosystems: a systematic map protocol. *Environ. Evid.* **9**, 1–12 (2020).
65. Diener, E., Oishi, S. & Lucas, R. E. National accounts of subjective well-being. *Am. Psychol.* **70**, 234–242 (2015).
66. Arnstein, S. R. A ladder of citizen participation. *J. Am. Inst. Plan.* **35**, 216–224 (1969).
67. Mangubhai, S. & Lawless, S. Exploring gender inclusion in small-scale fisheries management and development in Melanesia. *Mar. Policy* **123**, 104287 (2021).
68. Olsson, P. & Folke, C. Local ecological knowledge and institutional dynamics for ecosystem management: a study of Lake Racken watershed, Sweden. *Ecosystems* **4**, 85–104 (2001).
69. Pomeroy, R. S., Pollnac, R. B., Katon, B. M. & Predo, C. D. Evaluating factors contributing to the success of community-based coastal resource management: The Central Visayas Regional Project-1, Philippines. *Ocean Coast Manag.* **36**, 97–120 (1997).

70. Frey, B. S. & Stutzer, A. Happiness prospers in democracy. *J. Happiness Stud.* **1**, 79–102 (2000).
71. Stutzer, A. & Frey, B. S. Political participation and procedural utility: an empirical study. *Eur. J. Polit. Res.* **45**, 391–418 (2003).
72. Techera, E. in *Managing Environmental Justice* (ed. Pavlich, D.) 143–164 (Rodopi, 2010).
73. Leisher, C. et al. Measuring the benefits and costs of community education and outreach in marine protected areas. *Mar. Policy* **36**, 1005–1011 (2012).
74. Ferraro, P. J. & Hanauer, M. M. Through what mechanisms do protected areas affect environmental and social outcomes? *Philos. Trans. R. Soc. B* **370**, 20140267 (2015).
75. Veitayaki, J., Aalbersberg, B., Tawake, A., Rupeni, E. & Tabunakawai, K. *Mainstreaming resource conservation: the Fiji locally managed marine area network and its influence on national policy*. Resource Management in Asia-Pacific Working Paper No. 42 (The Australian National University, 2003); https://openresearch-repository.anu.edu.au/handle/1885/40990
76. Hawe, P., Shiell, A. & Riley, T. Complex interventions: how 'out of control' can a randomised controlled trial be? *Br. Med. J.* **328**, 1561–1563 (2004).
77. Minary, L. et al. Which design to evaluate complex interventions? Toward a methodological framework through a systematic review. *BMC Med. Res. Methodol.* **19**, 92 (2019).
78. Stata: Release 17. (StataCorp, 2021); https://www.stata.com/bookstore/users-guide/
79. Rothman, K. J. Six persistent research misconceptions. *J. Gen. Intern. Med.* **29**, 1060–1064 (2014).
80. Rothman, K. J. No adjustments are needed for multiple comparisons. *Epidemiology* **1**, 43–46 (1990).
81. Armstrong, R. A. When to use the Bonferroni correction. *Ophthalm. Physiol. Opt.* **34**, 502–508 (2014).
82. Rubin, M. When to adjust alpha during multiple testing: a consideration of disjunction, conjunction, and individual testing. *Synthese* **199**, 10969–11000 (2021).
83. Streiner, D. L. Best (but oft-forgotten) practices: the multiple problems of multiplicity—whether and how to correct for many statistical tests. *Am. J. Clin. Nutr.* **102**, 721–728 (2015).
84. Oster, E. Unobservable selection and coefficient stability: theory and evidence. *J. Bus. Econ. Stat.* **37**, 187–204 (2019).

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Author contributions

T.O., M.M., S.M., A.T. and M.T.-V. designed research. T.O., M.M., S.M., A.J., A.T. and M.T.-V. performed research. T.O. analysed data. T.O., M.M., S.M., H.G., A.J., A.T. and M.T.-V. wrote the paper.

Competing interests

The authors declare no competing interests.

Additional information

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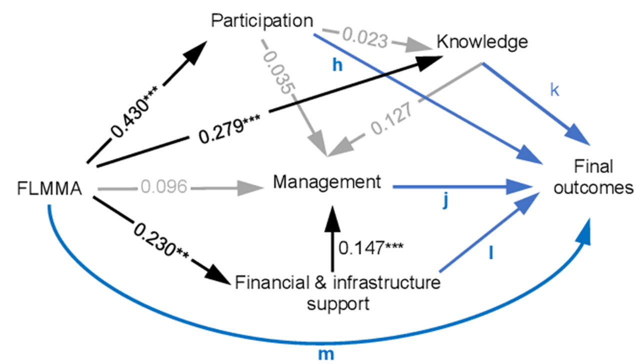
a.



b.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
path h	0.049 (0.053)	0.112 (0.083)	0.016 (0.211)	-0.052 (0.042)	-0.006 (0.076)	-0.073 (0.059)	-0.110 (0.855)	0.015 (0.051)	0.034 (0.060)	0.050 (0.056)	0.059 (0.192)	0.131*** (0.041)
path j	0.054 (0.111)	-0.320* (0.179)	0.108 (0.461)	-0.103 (0.135)	-0.102 (0.130)	0.067 (0.092)	-2.572* (1.376)	-0.162 (0.134)	0.029 (0.118)	0.099 (0.120)	-0.230 (0.306)	0.035 (0.073)
path k	-0.200* (0.109)	-0.007 (0.216)	-0.182 (0.450)	-0.155** (0.069)	0.058 (0.161)	0.062 (0.076)	-0.688 (1.168)	-0.019 (0.103)	-0.174 (0.127)	-0.036 (0.109)	0.153 (0.272)	-0.036 (0.093)
path l	-0.075 (0.087)	0.052 (0.114)	0.180 (0.366)	0.004 (0.064)	0.062 (0.109)	-0.108 (0.081)	-1.141 (1.172)	0.088 (0.093)	0.012 (0.080)	-0.049 (0.101)	-0.069 (0.186)	0.201*** (0.049)
path m	0.084 (0.119)	0.371 (0.226)	-0.416 (0.519)	0.257*** (0.090)	0.018 (0.130)	0.198** (0.094)	-0.982 (1.644)	0.079 (0.104)	0.091 (0.116)	0.005 (0.105)	0.592** (0.259)	0.117* (0.069)
CD	0.687	0.706	0.636	0.675	0.638	0.662	0.682	0.634	0.655	0.647	0.639	0.625
SRMR	0.016	0.016	0.016	0.016	0.016	0.016	0.019	0.015	0.016	0.019	0.016	0.017
n	146	146	146	146	146	146	145	131	128	132	146	146

Extended Data Fig. 1 | Full set of SEM results depicting pathways from FLMMA to final outcomes via hypothesized mechanisms. a. Causal model showing relationships to and between mechanisms (black pathways). Blue pathways vary by final outcome. **b.** Coefficients (standard errors in parentheses) for (blue) pathways (h, j, k, l, m) leading to final outcomes, listed as follows: (1) Village assets, (2) Household assets, (3) Diversity of income activities, (4) Non-dependence on fisheries for income, (5) Diversity food-gen activities, (6) Non-dependence on fisheries for food, (7) Satisfied with food from sea, (8) Fish catch, (9) Reef health good, (10) Mangrove not declined, (11) Subjective wellbeing, (12) Perceived management benefits. Coefficient of determination (CD) shows the fraction of variation (variance) explained by a model (higher values indicate better fit). The standardized root mean square residual (SRMR) describes the standardized difference between the observed correlation and the predicted correlation (values <0.08 indicate a good fit). †Missing observations are due to non-answers (refusal to answer or 'don't know') except for outcomes (9) and (10) which only have responses from villages with reefs or mangroves. Level of significance: *p < 0.1, **p < 0.05, ***p < 0.001 (two-sided tests).

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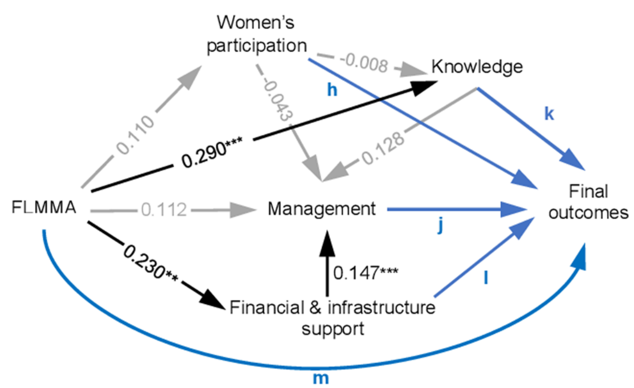
a.



b.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
path h	0.037	0.506**	-0.191	-0.009	0.328**	-0.220**	0.121	4.620***	0.096	-0.010	0.703*	0.101
	(0.107)	(0.223)	(0.431)	(0.086)	(0.128)	(0.110)	(0.110)	(1.738)	(0.128)	(0.118)	(0.371)	(0.076)
path j	0.061	-0.281	0.092	-0.111	-0.065	0.045	-0.144	-2.171*	0.044	0.113	-0.187	0.060
	(0.110)	(0.173)	(0.461)	(0.135)	(0.142)	(0.085)	(0.136)	(1.202)	(0.116)	(0.120)	(0.266)	(0.074)
path k	-0.197*	-0.000	-0.181	-0.157**	0.056	0.058	-0.020	-0.749	-0.170	-0.035	0.159	-0.030
	(0.110)	(0.222)	(0.450)	(0.071)	(0.160)	(0.075)	(0.101)	(1.094)	(0.123)	(0.110)	(0.286)	(0.089)
path l	-0.065	0.049	0.188	-0.010	0.060	-0.114	0.092	-1.175	0.024	-0.024	-0.098	0.231***
	(0.089)	(0.117)	(0.364)	(0.067)	(0.111)	(0.075)	(0.092)	(1.110)	(0.081)	(0.099)	(0.175)	(0.053)
path m	0.102	0.363	-0.374	0.240***	-0.059	0.196**	0.056	-1.856	0.079	0.004	0.543**	0.151**
	(0.122)	(0.229)	(0.525)	(0.087)	(0.118)	(0.091)	(0.108)	(1.553)	(0.113)	(0.104)	(0.261)	(0.073)
CD	0.705	0.731	0.660	0.697	0.662	0.679	0.655	0.695	0.676	0.685	0.659	0.647
SRMR	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.008	0.005	0.009	0.006	0.006
n†	145	145	145	145	145	145	144	130	127	131	145	145

Extended Data Fig. 2 | SEM results, participation operationalized in terms of women's participation. a. Causal model showing relationships to and between mechanisms (black pathways). Blue pathways vary by final outcome. **b.** Coefficients (standard errors in parentheses) for (blue) pathways (h, j, k, l, m) leading to final outcomes, listed as follows: (1) Village assets, (2) Household assets, (3) Diversity of income activities, (4) Non-dependence on fisheries for income, (5) Diversity food-gen activities, (6) Non-dependence on fisheries for food, (7) Satisfied with food from sea, (8) Fish catch, (9) Reef health good, (10) Mangrove not declined, (11) Subjective wellbeing, (12) Perceived management benefits. Coefficient of determination (CD) shows the fraction of variation (variance) explained by a model (higher values indicate better fit). The standardized root mean square residual (SRMR) describes the standardized difference between the observed correlation and the predicted correlation (values <0.08 indicate a good fit). †Missing observations are due to non-answers (refusal to answer or 'don't know') except for outcomes (9) and (10) which only have responses from villages with reefs or mangroves. Level of significance: *p < 0.1, **p < 0.05, ***p < 0.001 (two-sided tests).

Extended Data Table 1 | Indicators used to measure intermediate and final outcomes

Outcomes	Indicator	Description
Final outcomes		
Economic wellbeing & livelihoods	Village-level infrastructure	Index of village-level infrastructure and assets (L)
	Household-level assets	Index of key assets owned by households in the village (L)
	Diversification (for income)	Total number of activities that villagers engage in for income (L)
	Non-dependence on fisheries for income	Whether fisheries are *not* the main source of income in the village† (binary) (L)
Food security	Diversification (for food)	Total number of activities that villagers engage in for food, and other food sources (W)
	Non-dependence on fisheries for food	Whether fisheries are *not* the main source of food in the village† (binary) (W)
	Satisfaction with food from the sea	Whether people are "generally happy" with the amount and variety of food from the sea (binary) (W)
	Fish catch	Number of fish bundles collected per week on average per household (where a bundle of large, medium and small fish has 1-4, 6-8 and 8-12 fish respectively) (count) (W)
Perceived ecological health	Perceived coral reef status	Whether coral reef is in "good" or "bad" health as described using photos of reefs in both conditions (binary) (F)
	Perceived mangrove cover change	Whether mangrove cover in *iqoliqoli*‡ has not declined over time (binary) (F)
Subjective wellbeing	Subjective well-being	Mean subjective wellbeing across leaders, women, fishers and youth per village (mean of responses to 11-pt Cantril scale) (ALL)
Perceived benefits	Perceived benefits from *iqoliqoli* management	Benefits to the community from *iqoliqoli* management out of increased fish catch, increased sales of marine produce, improved livelihoods, increased knowledge about marine resources and how to manage the *iqoliqoli,* and increased cooperation (proportion selected) (L)
Intermediate outcomes (mechanisms)		
Participation (proxy for political empowerment)	Village-level participation	Mean participation in making marine resource rules for the *iqoliqoli*† across leaders, women, fishers and youth (mean of 5-pt scale, where 1=no participation/no meetings* to 5=full participation of social group in meetings) (ALL)
Management of marine resources	Whether a village has the basic tools to manage it's *iqoliqoli*	Whether a village has all of the following: rules regulating fisheries, monitoring (proxied by presence of a fish warden), penalties for breaking rules, enforcement of penalties (binary) (L)
Marine resource knowledge	Village-level perceived knowledge about marine resources	Mean perceived knowledge about factors influencing reef health, fisheries diversity and fisheries quantity over leaders, women, fishers and youth (continuous) (ALL)
Financial &/or infrastructure support	Provision of financial and/or infrastructure support	Whether a village has had financial and/or infrastructure inputs from partner(s) for LMMA functions since joining FLMMA (binary) (L)

Letters in parentheses show which key informant social group provided this data: (L)=leaders, (W)=women, (F)=fishers, (ALL)=all key informant social groups. † These variables have been re-oriented so that higher values correspond with desired outcomes (that is lower dependence on fisheries), in common with all other outcomes. ‡As noted in the main text, *iqoliqoli* refers to the customary fishing ground. We use this term in the table for reasons of space. *For participation, we combined 'no meetings' with 'no participation' responses (Supplementary Information 2).

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Software and code

Policy information about availability of computer code

Data collection	No software was used to collect the data for this study
Data analysis	All analysis was conducted using Stata 17.0; specific commands used are listed in the Methods section of the article

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Summary data that support the findings of this study are available within the paper and the Supplementary Information. Raw data are available on request from the corresponding author with reasonable restrictions, as these data contain information that could compromise research participant privacy and consent.

Human research participants

Policy information about studies involving human research participants and Sex and Gender in Research.

Reporting on sex and gender	Although the main unit of analysis in this study is the village, we conduct additional analyses focusing on the key social groups (leaders, women's group, fisher's group) that might benefit from increased participation in decision-making, and enhanced knowledge about marine resources. We find an interesting result with regards to women's participation in decision-making, namely that it appears to positively influence a range of outcomes including household assets and food security. We propose that future research should apply a gender lens to understanding participation in marine resource decision-making, and how it may deliver key sets of outcomes.
Population characteristics	Taking our sampling frame of 265 villages as our population of interest (see "Sampling strategy"), these villages are on average 4.3km from the nearest road and 42km from the nearest municipal market; their customary fishing grounds (iqoliqoli) cover a mean area of 247 square metres and contain 177 square meters (mean) of coral cover. The average number of villages sharing each iqoliqoli is 5.2. The nearest previous LMMA adopter (i.e. village that had joined FLMMA before they did) is 13km away on average, and the proportion of FLMMA villages in this sampled population is 58.8%. See Supplementary Table S3 for a breakdown of covariates by FLMMA membership ('unmatched' columns).
Recruitment	Participants generally self-selected into the key informant groups if they were present during the welcome ceremony (the 'sevusevu', Supplementary Information 1). In some cases, specific individuals were also suggested by village leaders and/or other member of the same social group who were present at the sevusevu ceremony, and these suggestions followed by enumerators who would ask these potential respondents if they wanted to participate. However, the decision to participate was made by each individual. Given that self-selection bias is a consideration for all studies involving key informant interviews with consenting participants, we opted to obtain data from small groups of key informants rather than from individual key informants to allow for deliberation and pooling of knowledge, potentially improving the accuracy of responses; we expect quantitative responses provided through group discussion and consensus to be less susceptible to biases from individual values or characteristics (for discussion see Supplementary In formation 1).
Ethics oversight	This research was approved by the Middlesex University Ethical Review Board (application number 8030) on 17th July 2019. Consent was obtained from the village chief before any interviews were conducted, followed by individual consent from key informants.

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

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Behavioural & social sciences study design

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Study description	This is a quantitative study which uses primary village-level data, generated using key informant group surveys, to identify the impact of a national community-based natural resource management initiative - the 'locally-managed marine areas' (LMMA) network in Fiji.
Research sample	Our research sample consists of coastal villages (within 1km of the water) throughout Fiji that we had spatial data for (needed to perform statistical matching). We excluded the distant island groups of excluding Lau and Rotuma, which we could not include due to the difficulty and cost of accessing these islands. The sample was selected using matching approaches to allow for causal inference.
Sampling strategy	To identify causal impacts of FLMMA membership, we first identified 581 coastal villages in Fiji (excluding Lau and Rotuma) located within 1km of the water that we had spatial data for (source: Ministry of Lands & Resources). FLMMA villages (identified using the Fiji LMMA 2019 village member database) were selected in two 'cohorts' based on year of adoption: cohort 1 includes villages with LMMAs established ~15 years ago (n=94), and cohort 2 includes villages with LMMAs established ~10 years ago (n=88). In developing our sampling frame, we imposed 1km buffers to minimise ecological spill-over effects, removed villages with other coastal-management interventions, and ensured that non-FLMMA villages did not share fishing grounds with FLMMA villages; this leaves a final sampling frame of 265 villages, from which we selected our final sample of study villages. Using this sampling frame, we used one-to-one propensity score matching without replacement to select non-FLMMA villages so that they resembled FLMMA villages at baseline with regards to covariates expected to influence both LMMA adoption and impacts (outlined in Supplementary Information 2). This resulted in a final sample of 152 villages, of which half are members of FLMMA and half are not.
Data collection	We collected data through interviews with groups of key informants between Oct. 2019 – Mar. 2020. Group interviews were conducted with four groups of key informants – village leaders, women, fishers, and the youth (defined as people between the ages

of 18-35). In advance of the interviews, requests were sent to the head of the group (if relevant) along with other members of the group prior to the visit, to ensure that people were available for the interview. Consent was obtained from the village chief before any interviews were conducted, followed by individual consent from key informants. Enumerators collected data on printed surveys; Importantly, neither the instructions nor the questions explicitly refer to "FLMMA" or "LMMAs", and all questions about marine resource management and other LMMA-related factors were framed in terms of the customary fishing ground ('iqoliqoli'). This was done to minimise social desirability response bias among respondents in FLMMA villages (details in supplementary Information 2). No-one else was present during interviews other than enumerators teams and participants; enumerators were not aware how the data would be used, the research questions underlying the study or the specific analyses that would be conducted on the data, to minimise any possible influences on how respondents answered questions.

Due to unforeseen events during fieldwork (see "non-participation"), our final sample includes data from 134 matched villages (selected through matching), and data from additional unmatched villages (n=11 FLMMA and n=1 non-FLMMA villages). However, covariate balance for the final sample (Supplementary Information Table S5) compares favorably to that of the matched sample (Supplementary Information Table S3), hence we opt to use all the data for analysis. The final sample size is 146 villages. We were able to the conduct interviews with the leaders' and women's groups in all (n=146) villages in the final sample, fishers in 143 villages, and youth in 136 villages (ten villages didn't have a youth group).

Timing

Data collection commenced in October 2019; there was a break from December 19th to January 12th for the Christmas period. Data collection resumed January 12th but was terminated early in March 2020 due to the onset of the Covid-19 pandemic, resulting in a final sample size of 146 villages. The teams spent an average of 60 minutes on interviews, although leaders' interviews averaged 75 minutes.

Data exclusions

No data was excluded

Non-participation

Ten selected villages did not participate in the study due to either last-minute commitments, absence of certain groups, or conflicts within the village. With regards to conflicts, although not a common occurrence, we were pre-warned by the provincial office of any ongoing traditional disputes over the leadership titles in a few villages in the sample and these were dropped to avoid exacerbating conflict and maintain data quality. Another two villages had recently merged into one village, so these were interviewed together (accounting for one fewer village in the final sample). Finally, due to the onset of Covid-19, a further 11 villages could not be interviewed.

Randomization

As noted under 'Sampling Strategy', we used one-to-one propensity score matching without replacement to select non-FLMMA villages so that they resembled FLMMA villages at baseline with regards to covariates expected to influence both LMMA adoption and impacts. The covariates used in matching were: distance to nearest road, distance to nearest market, distance to nearest previously-established LMMA, area of customary fishing ground, coral reef cover and number of other villages sharing the fishing ground.

Reporting for specific materials, systems and methods

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☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☒	☐ Clinical data
☒	☐ Dual use research of concern

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
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