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An Example from Tanzania

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The Role of Incentives for Sustainable Implementation of Marine Protected Areas: An Example from Tanzania

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Abstract

Although Marine Protected Areas (MPAs) provide an increasingly popular policy tool for protecting marine stocks and biodiversity, they pose high costs for small-scale fisherfolk who have few alternative livelihood options in poor countries. MPAs often address this burden on local households by providing some benefits to compensate locals and/or induce compliance with restrictions. We argue that MPAs in poor countries can only contribute to sustainability if management induces changes in resource-dependent households' incentives to fish. With Tanzania's Mnazi Bay Ruvuma Estuary Marine Park (MBREMP) and its internal villages as an example, we use an economic decision modeling framework as a lens to examine incentives, reaction to incentives, and implications for sustainable MPA management created by park managers' use of enforcement ("sticks") and livelihood projects ("carrots"). We emphasize practical implementation issues faced by MBREMP managers and implications for fostering marine ecosystem sustainability in a poor country setting.

Key Words: marine protected areas, sustainable marine reserves, Tanzania, practical enforcement, marine-dependent livelihoods

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1. Introduction

Marine Protected Areas (MPAs) are increasingly popular policy tools that, in contrast to terrestrial protected areas, typically have a central goal of protecting livelihoods in addition to protecting marine biodiversity and particular sites for recreation (Carter, 2003). As with terrestrial protected areas, MPAs often seek to address their negative impact on local households by providing some benefits to induce compliance with the restrictions and defray the burdens of the park. Yet even so, when applied in poor countries, the MPA restrictions can be particularly costly for small-scale fisherfolk who have few alternative livelihood options—especially in the short run before fish stocks have had a chance to recover.

In this paper we argue that marine protected area management in poor countries, where nearby households are typically highly dependent on the resources in the protected area, is only likely to contribute to ecological sustainability if management actions induce changes in the resource-dependent households' incentives to fish. The likelihood of MPA policies contributing to livelihood sustainability depends on the relative size of the benefits of alternative income projects and the burdens on households from the imposition of the MPA's associated rules, regulations, and fishing restrictions. We focus particularly on the early years of MPA implementation when stocks are low and before they have a chance to recover because this is the particularly tricky time when MPA managers need to foster cooperation with villagers whilst also restricting fishing in the park to ensure that stocks recover. We therefore abstract away from the fish ecology and the long run equilibrium. If the MPA managers cannot ensure cooperation of villagers in the short term there cannot be a sustainable long run equilibrium.

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With Tanzania's Mnazi Bay Ruvuma Estuary Marine Park (MBREMP) and its internal villages as an example, we use an economic decision-modelling framework as a lens to examine the incentives, reaction to incentives, and implications for sustainable MPA management created by park manager's use of enforcement ("sticks"), livelihood projects ("carrots"), and fishing gear exchange (technological intervention) to promote marine conservation. We emphasize in this paper the practical implementation issues faced by the MBREMP managers and the implications of those difficulties for the marine park's ability to foster village cooperation with marine park objectives in a poor country setting. In particular, we look at how a village's location and therefore comparative advantage in fishing or agriculture influences the village's decision to accept the park and its rules and regulations, and why MBREMP's strategy of "collaborative management through community participation" has led to uneven acceptance of the MPA's rules and regulations and engendered conflict particularly with the villages most dependent on fishing (MNRT, 2005, p. 30).

Much of the academic research on MPAs focuses on how the creation of an MPA, which closes an area to fish harvest, affects fish populations and fish harvests in the MPA and in the broader region. Most papers reflect characteristics of fish biology including the dispersal of fish from "sources"—which might be the MPA—to less densely populated "sink" sites where fishing is permitted. Some papers show that such a source-sink set up created through an MPA is not likely to offset the costs to fishermen of not being able to fish in the MPA region (Carter, 2003; Hannesson, 1998; Sanchirico and Wilen. 2001; Smith and Wilen, 2003). Only a small academic resource economics literature examines small-scale fisheries in developing countries. The focus of this literature tends to be livelihoods and poverty (Béné, 2005); the impact of fishermen's risk aversion (Eggert and Lokina 2007); and sustainable catches. In general, few papers consider the impact of an MPA on local fisherfolk, their welfare, and—of particular importance to our research presented here—how MPAs and related policy interventions change people's incentives to cooperate with an MPA and to change their behaviour accordingly in the early years of MPA implementation before stocks have recovered. In a key exception, Gjertsen (2005) uses an economic framework to examine when win-win situations arise in the use of MPAs to improve reef conservation and rural well-being. She finds a large role for successful alternative livelihood projects in the ability to create a win-win situation. Silva (2006), using Tanzania as a case study, suggests that alternative income generating activities do not conclusively reduce pressure on fisheries or improve the livelihoods of fisherfolk.

The large academic literature on the management of common property resources in general includes models and policy discussions of the role of management institutions and of incentives to cooperate that builds on the seminal work by Ostrom (e.g. Ostrom, 1990; Ostrom et al. 1994; Ligon and Narain, 1999). Much of this literature focuses on terrestrial protected areas in developing countries, and increasingly emphasises the potential negative impact of protected areas on local people and mechanisms to create incentives for cooperation by local people (recent examples include Albers and Robinson, 2010). Similarly, several recent economic models look at resource management by groups of landowners in a spatially explicit game model but such approaches have not been applied in the MPA setting (Busby and Albers, 2010; Albers et al., 2008)

In the following Section 2, we provide some background information on MBREMP, informed by our multiple visits in 2008 and 2010. In Section 3 we develop a simple conceptual model of a marine park in which a number of villages at different distances from the fishery and agricultural land make labour allocation decisions between activities. The MPA manager can use enforcement or incentives to change the pattern of fishing and therefore the pressure on the park resources. We consider how these different management tools affect not just the total volume of fish caught but the villagers' livelihoods depending on their village location. We abstract away from the dynamics of fish recovery to focus on how the initial stages of MPA implementation changes harvesting behaviour. In Section 4, we use this model as a lens to examine incentives, reaction to incentives, and implications for more sustainable MPA management. In Section 5 we conclude with a more general discussion of our findings and policy implications.

2. Management of Mnazi Bay Ruvuma Estuary Marine Park

Mnazi Bay Ruvuma Estuary Marine Park (MBREMP) is located in Mtwara Rural District, Mtwara Region, in southern Tanzania. MBREMP covers an area of approximately 650km^2, approximately 430km^2 of which is sea, including islands and mangrove forests and the remainder 220km^2 is terrestrial. The park was gazetted in 2000 and originally enclosed 11 villages (Madimba, Mitambo, Litembe, Tangazo, Kihimika, Mahurunga, Kitunguli, Kilambo, Mngoji, Msimbati and Nalingu) along Mnazi Bay and the Ruvuma River's mangroves. More recently four additional villages have been incorporated that have been created out of the existing villages: Mnete (Nalingu), Mnaida (Tangazo), Mtandi (Msimbati) and Mkubiru (Mnawene). The location of these villages within the park are shown in Figure 1.

Figure 1. Schematic Map of MBREMP

Note: The dashed green line represents borders of the park, the green area marks the mangrove forest, and dots represent the villages.

The park management team is headed by the warden in charge aided by senior wardens in each department. MBREMP has four active working departments that include administration, law enforcement, community conservation, and research and monitoring. One of the key stated objectives of the Park is to enable local and Government stakeholders to promote sustainable resources use and biodiversity conservation in the park. The park managers are attempting to achieve these objectives through a reduction of extractive pressure on the marine resources, using a combination of strategies for a sustainable harvesting regime and developing alternative or supplementary income generating activities for people who traditionally depend on marine resources of the Park. We can therefore see that, unlike the assumptions in much of the marine protected area literature, MBREMP permits fishing within the protected bay.

2.1 Characterising the Villagers Living in the Park

The population in the park was estimated at 28,000 in 2004, and most villagers are involved in farming or fishing. The number of individuals involved primarily in marine resource extraction was estimated to be 1400, about two thirds of whom use traditional dug out canoes. Most fishers are artisanal fishers, operating within shallow water particularly in the intertidal areas, estuary and mangrove creeks. A large number of households do not fish directly but are involved in marine-related and coastal activities. The importance of fishing for each village varies considerably. A number of villages are particularly dependent on marine fishing and include Mngoji, Msimbati, Mkubiru, Nalingu and Mnete. A few villages are involved in river fisheries, particularly Kitunguli and Mahurunga but even so the most important activity in these villages is farming. Still other villages have little if any involvement in fishing and depend primarily on farming. Not surprisingly, these tend to be the villages furthest from the water and include Kilambo and Kihimika (Malleret-King et al., 2006).

2.2 Formal Rules and Regulations of MBREMP

The Law Enforcement Department is composed of six park rangers with the following duties: enforcement of marine parks and reserve regulations; conducting regular patrols within the park boundaries to ensure compliance to the park regulations; regular checking of fishing gears; operating and keeping records of all radio communications; assisting the prosecution process; day to day patrol activities including scuba diving. There is a comprehensive list of rules and regulations governing MBREMP. Key amongst these include: the prohibition of particular fishing technologies including beach seine nets (including those known locally as juya, kavogo, juya la kusini, juya la kojani, kokoro, and mtando); activities that damage coral; mangrove cutting for commercial sale; and the use of nets with mesh size less than 2.5 inches. Fishing within the MBREMP protected area is, according to the regulations, restricted to artisanal fishers who are resident in one of the villages located within the MPA. The process according to the written regulations is for these fishers to be issued a fishing licence and for illegal fishing gear to be phased out with due compensation.[1]

[1] The Rules and regulation of the marine park are summarized in the General Management Plan of the MPA in Chapter seven

2.3 Description of MBREMP's Interventions

Gear Exchange

The first MBREMP initiative in 2006 was gear exchange in which villages were offered large mesh nets in exchange for the illegal small mesh nets. Subsequent gear exchanges occurred in 2007 and 2008. In the first exchanges, villagers were given 5-6 inch mesh nets but more recent exchanges have focuses on 3 inch mesh nets. Villagers who fished were expected to switch from their traditional small-mesh nets (typically less than one inch square and often much finer) to more costly large-mesh nets (to be legal, at least two and a half inches square) that are too large to catch most of the fish that are found in the bay. The large-mesh nets are appropriate for fishing on the open seas, but to do so fishermen need large engine boats that most cannot afford. In the long run, the intention is that fish stocks in the bay recover and the average size of fish in the bay increases such that these larger-mesh nets would be appropriate for sustainable fishing in the bay. However, this situation appears nowhere close to being reached and there are still very few larger fish in the bay.

Enforcement

The implementation of an MPA in an area where there were formerly no enforced rules implies access restriction for fishers through enforcement. Indeed we can characterise an MPA fishing ground as one in which access and technology restrictions are enforced and immediately after the introduction of MBREMP the focus was on enforcing the rules, a "sticks" only approach. In MBREMP the park managers focused on fishing technology, particularly net mesh size and dynamite fishing, deciding early on that, despite the regulations that only those residing in the MPA park boundaries should be allowed to fish in the MPA, this was not a regulation that the park management felt able to enforce. The MBREMP patrols the bay's fishing areas by boat and monitors fish land sites but funding constraints limit the days per month for such detection activities. In villages that cooperate with the MBREMP, village resource management councils provide some labour per month for these patrol activities to supplement the park's guards. Although the state regulations concerning gear state that small mesh nets were to be phased out with compensation such as the new large mesh nets, we find that fishers who have not been involved in a gear exchange programme who are caught with small nets are punished punitively with both their nets and boats being confiscated.

Income-Generating Projects

When MBREMP was initially being set up, the marine park managers offered each village a similar deal: villagers were encouraged to "accept" the park, which in practice meant to cooperate with the rangers and the park rules, particularly with regards to using only legal fishing gear, in exchange for various alternative livelihood and fishing technology projects. These projects included bee keeping, fish ponds, gear exchange in the form of giving up small-mesh nets in exchange for large-mesh nets, and boats and engines for fishing outside the bay (though the latter because of their cost have only been offered to a few fishing groups). There have been a number of phased formal projects and initiatives implemented by the MBREMP management team or NGOs, including WWF (Table 1).

Table 1. Major Projects and Initiatives Implemented by MBREMP Management 2006–2009

	Importance of fishing	Phase 1 gear exchange 2006	Bee keeping 2006	Phase 2a gear exchange 2007	Fish farming 2008	Phase 3 gear exchange 2008	Offshore fishing project 2008	Bee keeping 2009	Dairy cattle	No of distinct initiatives
Nalingu/Mnete	High						X			1
Msimbati	High				X	X	X			2
Mkubiru	High					X	X			2
Mngoji	Medium			X	X	X				2
Madimba	Medium			X		X			X	3
Mitambo	Low	X		X		X			X	4
Litembe	Low	X		X	X	X		X	X	6
Kihimka	Low			X		X		X		3
Kitunguli	Low					X				1
Tangazo	Very low	X	X	X	X	X			X	5
Kilambo	Very low	X		X	X	X			X	4
Mahuruga	Very low					X				1

Source: Park records; Harrison, P. 2005; Authors' survey 2010.

3. A Model

In this model we consider a set of villages that are differentiated by their spatial location within an MPA. Each village *i* can conceptually be identified by coordinates (T^F, T^A) which represent the time cost for a villager living in that village to get to the fishing ground and to agricultural land respectively. The MPA manager then introduces a number of interventions designed to protect the MPA. Enforcement, a "stick," is represented as patrol activity that creates a probability q that a villager will be caught fishing and punished with a fine F. The "carrot" is a livelihood activity distinct from fishing or agriculture and that require a fixed quantity of labour, such as bee keeping. A third intervention, the technological intervention, is gear exchange through which fishers exchange their commonly-used small-mesh nets for large mesh-nets, which changes the economics of fishing and switches the villager from an illegal to a legal fishing technology. If villagers accept the new gear, their catch goes down because of the large mesh size but they no longer face a probability of being fined for illegal fishing.[2] We consider the villager's optimal allocation of labour between agriculture and fishing before and after the interventions to determine how these interventions affect both the total catch in the fishery and villagers' livelihoods. By using a model with heterogeneous villages differentiated by their distance from the fishery and agricultural land, we can see how interventions affect villagers differently depending on their location, how this spatial pattern affects the overall impact of the MPA interventions on fish catch, and how village location affects cooperation with the MPA.

3.1 A Representative Villager's Optimisation

We consider a representative villager in village *i* who has a fixed quantity of labour L that he can allocate to fishing, L^F, or agriculture, L^A to maximise his expected returns to labour V. We keep the production functions for fishing and agriculture simple functions only of labour, with diminishing returns to labour for both activities (respectively ϕ and α), a labour time cost of accessing the fishery (T^F) or agricultural area (T^A), and the prices of fish, G, and agricultural output, A. With no MPA interventions the villager's optimisation can be written:

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[2] With time, large-mesh nets should permit the recovery of fish stocks and increase the average size of fish, in which case both stocks and catch are higher and sustainable. However, in this paper we focus on the short run because typically poor fishermen, as we find in MBREMP, have a short term time horizon and cannot go without resources in the short run. Moreover, whether the park is sustainable depends in large part on whether sufficient villages accept the park and its rules in the early days after its introduction.

$$\max_{L^F}\{V\} = \max_{L^F}\left\{G \cdot L^{F^{\phi}} + L^{A^{\alpha}}\right. \qquad [1]$$

Where $L = L^F + L^A + \delta^F \cdot T_i^F + \delta^A \cdot T_i^A,\ L^F \geq 0\ ;\ L^A \geq 0\ ;$
$T_i^F \geq 0\ , T_i^A \geq 0;\ \ \delta^F = 1\ \text{if}\ T_i^F > 0\ \text{else}\ \delta^F = 0;\ \ \delta^A = 1\ \text{if}\ T_i^A > 0\ \text{else}\ \delta^A = 0$

$\phi < 0, \quad \mu < 1, \quad \alpha < 1$

This model formulation is intentionally simple to provide a foundation from which to explore the interaction of MPA policy interventions and spatial heterogeneity of villages. There are three potential types of villages: “Fish Only”, where villagers only engage in fishing; “Agriculture Only”, ($\delta^F = 0$), where villagers only engage in agriculture ($\delta^A = 0$); and “Mixed”, where villagers engage in both agriculture and fishing ($\delta^A = 1$ and $\delta^F = 1$). To which category a village belongs is endogenous to the model parameters and in particular the time costs T_i^F and T_i^A (Robinson et al., 2002 uses a similar approach for categorising individual villagers depending on their use of forests).

The model forms a simple set of conditions:

$L^F = L - T^F$ and $L^A = 0$ for a Fish Only villager [2]

$L^A = L - T^A$ and $L^F = 0$ for an Agriculture Only villager

L^F is the solution to $\phi G \cdot L^{F^{\phi-1}} = \alpha A \cdot \left(L - L^F - T^F - T^A\right)^{\alpha-1}$ for a Mixed villager

Conceptually, a villager in a particular village would determine her returns to being Fish Only, Agriculture Only, and Mixed, and choose the type that gives her the maximum returns to her labour. A set of “critical” combinations of time costs $\left(T^F, T^A\right)$ identify the endogenous divisions among the different types of villages (as for Robinson et al., 2011).

We do not solve explicitly for an MPA manager optimisation. Rather, we show the trade-offs that the MPA manager faces between different interventions in terms of the impact on fish catch, the impact on villager livelihoods, and the differential impact on different villages depending on their location. We consider the three possible MPA manager’s interventions. The first, enforcement, we represent in the model as follows. The MPA imposes some exogenous fine

F on villagers caught using illegal fishing gear.[3] The probability of being caught q is a choice variable for the MPA manager.[4] Second, the returns to a livelihood project that a villager accepts are $P \cdot \bar{L}^P$ where $\bar{L}^P$ is the fixed labour time that the villager must spend on the project to get the returns $P \cdot \bar{L}^P$. Third, accepting gear exchange changes the returns to fishing effort V^F, $V^F = \mu G \cdot L^{F^\theta}$ where $\mu < 1$ and $\theta < 1$. Villagers can choose not to accept these last two interventions if they are better off without them. That is, they can choose to continue to fish illegally if offered gear exchange, and they can simply not adopt the livelihood project. The spatial heterogeneity of villages allows for heterogeneity in villages accepting these different interventions. The villager's optimisation with the three interventions become:

$$\max_{L^F}\{V\} = \max_{L^F}\left\{(1-q)G \cdot L^{F^\phi} - qF + A \cdot L^{A^\alpha}\right\} \quad \text{enforcement only}$$

$$\max_{L^F}\{V\} = \max_{L^F}\left\{\mu G \cdot L^{F^\theta} + A \cdot L^{A^\alpha}\right\} \quad \text{gear exchange only}$$

$$\max_{L^F}\{V\} = \max_{L^F}\left\{GL^{F^\phi} + A \cdot L^{A^\alpha} + P \cdot \bar{L}^P\right\} \quad \text{project only} \qquad [3]$$

$$\max_{L^F}\{V\} = \max_{L^F}\left\{(1-q)G \cdot L^{F^\phi} - qF + A \cdot L^{A^\alpha} = P \cdot \bar{L}^P\right\} \quad \text{enforcement and project}$$

$$\max_{L^F}\{V\} = \max_{L^F}\left\{\mu G \cdot L^{F^\theta} + A \cdot L^{A^\alpha} + P \cdot \bar{L}^P\right\} \quad \text{project and gear exchange}$$

Where $L = L^F + L^A + \delta^F \cdot T_i^F + \delta^A \cdot T_i^A$ without project

$L = L^F + L^A + \delta^F \cdot T_i^F + \delta^A \cdot T_i^A + \bar{L}^P$ with project

$L^F \geq 0$; $L^A \geq 0$; $\phi < 1$; $\mu < 1$, $\alpha < 1$, $T_i^F \geq 0, T_i^A \geq 0$;

$\delta^F = 1$ if $T_i^F > 0$ else $\delta^F = 0$;

$\delta^A = 1$ if $T_i^A > 0$ else $\delta^A = 0$.

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[3] In practice we have found that punishments are not proportional to the amount of illegal fishing, but tend to be confiscation of the illegal fishing gear and boat, which we proxy with a monetary fine.

[4] Naturally this choice of q has cost implications. Because the purpose of this paper is to demonstrate trade-offs in using different interventions in MPA management, we are not focusing on the full optimisation for the MPA manager.

Just as the village type is endogenous to the model so too is whether villagers in a particular village accept or reject a particular intervention. A village's type may change as a result of accepting a particular intervention, or a change in the level of enforcement. We run a set of simulations to illustrate how these three different interventions interact and alter fish catch and villager wellbeing.[5] To cover an array of possible locations, we simulate sixteen villages, each comprising one representative villager, differentiated by their location relative to the fishery and agriculture, where T^F and T^A can each be 0, 1, 2, or 3. For example, the village closest to the fishery and agricultural lands has time costs $\left(T^F, T^A\right)$ equal to (0,0) and the village furthest from both has time costs (3,3).

3.2 Model Results

We run simulations of the village decisions under different scenarios to illustrate the key points of the model about the incentives MPAs create, the village reaction to those incentives, and the resulting levels of fish harvest. We begin with a general model to generate a variety of results and then explore the subset of cases that apply in MBREMP in particular. To incorporate a full range of cases, we choose a base-line calibration that finds all three types of village—Fish only, Agriculture only, and Mixed—in response to the MPA's actions. After varying the parameters of the model across a series of simulations, exploring the set of results reveals how various levels and types of MPA interventions affect villages with heterogeneous location/opportunities, the village welfare, and the overall impact on fish catch. We emphasise the impact of the MPA manager's key intervention tools, specifically the probability of catching villagers fishing with illegal gear, q, and the benefits from a livelihood project.

The first set of simulations demonstrate the impact of enforcement only on each village's type, overall returns to village labour, and total fish catch for all 16 villages. For four villages along a spectrum of distance from fishery and agricultural land, Figure 2 graphs how individual returns to village labour change. We choose villages with coordinates (0,3), (1,2), (2,1), and (3,0) because these villages have the same total distance costs but different locations, which allows simple comparisons of the impact of interventions on the individual villages. Table 2 contains

[5] Analytical solutions cannot be generated for Mixed villages even for this simple model. Simulations allow us to explore how the different combinations of interventions that the MPA manager can employ affect fish catch, total, and individual village welfare and therefore total and individual village incentives to cooperate with the MPA.

the simulation results for each of four probabilities of being caught fishing illegally (q).[6] For each of the 16 village location types, the table indicates which the village's post-enforcement activity type: Fish Only, "F", Mixed, "M", or Agriculture Only, "A". In this simulation villagers do not have the option of fishing legally with large-mesh nets.[7] Villagers therefore make the choice as to continue fishing effort but with reduced effort, and risk being caught, or to stop fishing all together and undertake Agriculture Only. Because the fine is not proportional to the catch, villagers are more likely to be induced to stop fishing altogether than with a proportionate fine. With no enforcement, q=0, which mimics the situation without an MPA, villages furthest from agricultural land are Fish Only, and villages closest to agricultural land are Mixed (Table 1a). With low enforcement, q=0.2, all three types of village emerge (Table 1b), and with higher enforcement levels, q=0.4, no villages are Fish Only (Table 1c). With sufficiently high enforcement there is no fishing at all (Table 1d). In Figure 1a, not surprisingly, with increasing enforcement, the total fish catch decreases and village welfare decreases for every village but through non-linear relationships. The results depicted in Figure 1b show the impact on the four selected individual villages, (0,3), (1,2), (2,1), and (3,0). Although for this calibration the village closest to the fishery (0,3) is initially better off than the other villages, it is hardest hit by the MPA enforcement and, for all q>2.8, is worse off than all the other villages.

Table 2. Impact of Varying *q* on Villager Type

	Distance from agricultural land										
Distance from fishery	(a) q=0	0	1	2	3		(b) q=0.2	0	1	2	3
	0	M	M	F	F		0	M	M	M	F
	1	M	M	F	F		1	M	M	M	F
	2	M	M	F	F		2	M	M	M	F
	3	M	M	F	F		3	A	A	A	F
	(c) q=0.4	0	1	2	3		(d) q=0.6	0	1	2	3
	0	M	M	M	M		0	A	A	A	A
	1	A	A	A	A		1	A	A	A	A
	2	A	A	A	A		2	A	A	A	A
	3	A	A	A	A		3	A	A	A	A

[6] For this particular set of simulations we choose the following base-line calibration: G=5, A=3, L=10, α=0.7, q=0.2, F=5, ϕ=0.6, $L(P)$=2, P=1.3, μ=0.8, θ=0.5.

[7] In practice, typically these improved nets are costly and villagers cannot afford to purchase them, even if once purchased returns to fishing would be improved, but rather wait until they are offered by a project.

Figure 2a. Returns to Village Labour and Total Fish Catch

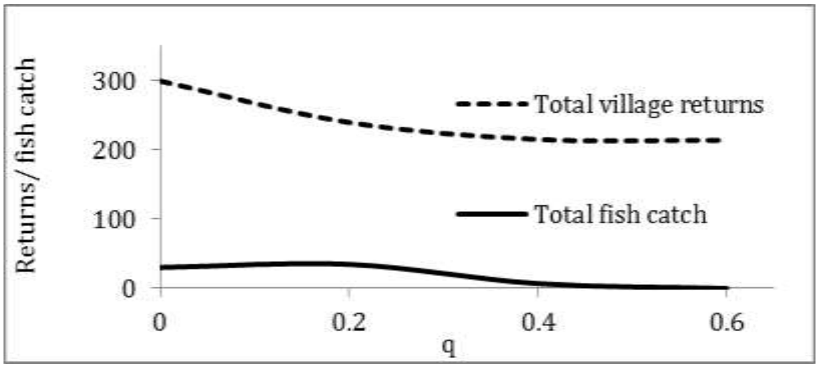
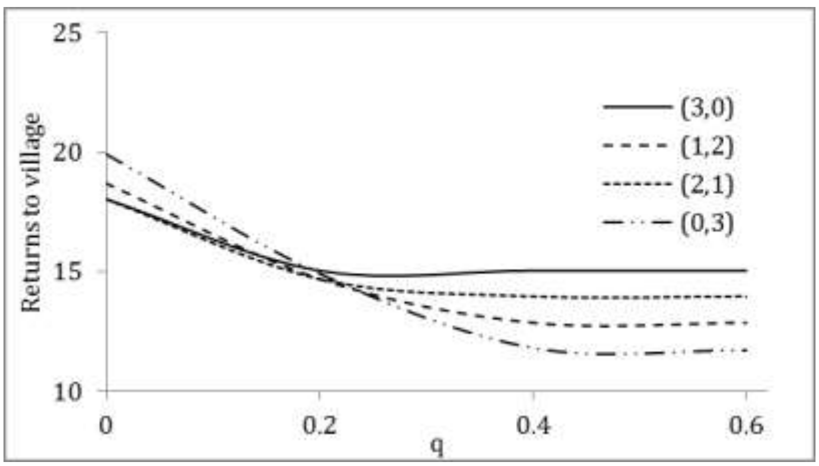


Figure 2b. Returns to Four Selected Villages as a Function of q



Offering a livelihood project similarly leads villages to consider reallocating some of their labour from fishing and/or agriculture to the project's activities, but they do not change their type because the marginal conditions are not changed. Villagers compare returns to their labour without and with the project and choose whether to accept or reject it. Because such livelihood projects are examples of "conservation by diversion," the labour requirement determines the maximum amount of labour that will be diverted from fishing to other activities, and therefore the maximum impact on the fish stocks. The greater the labour requirement, the greater the reduction in fishing in the MPA for those villagers that accept the project, but the less likely that villagers will accept the project because the marginal benefits of fishing and agriculture increase with decreasing time allocated to those activities. For projects offering low returns, ($P<1.1$), no villagers accept the project because they receive higher returns from their other activities. At higher returns, fishing-only villages are more likely to accept the project (Table 3 and Figure 3). Once all the villages have accepted the project, increasing returns to the project simply improves villagers' livelihoods without having an impact on fish catch (Figure 3b).

Because changing fishing technology is an important part of MBREMP's interventions, we consider the impact of gear exchange and how this interacts with the stick of enforcement and the carrot of a livelihood project. No villager accepts gear exchange if there is no enforcement of minimum net mesh size in the MPA because the legal gear reduces catch as a function of labour effort. When gear exchange is combined with a low level of enforcement (q=0.2), villages with the smallest total distance costs (summing the distance to agriculture and to fishing) of 0, 1, reject the gear's reduction in marginal fishing benefits and instead fish illegally, as do villages that are farthest from agriculture and at least one unit away from fishing (Table 3b). We can see that village (0,3) accepts the gear exchange and changes type from Fish Only to Mixed. Other villages accept the gear exchange and remain Mixed villages. Three villages that are distant from the fishery (3,0), (3,1) and (3,2) switch from Mixed to Agriculture Only villages. Although technically they accept the gear exchange, it is the enforcement that induces the change in village type and indeed, once Agriculture Only, they do not fish and so the gear type is not relevant.

Table 3. Impact of Varying *P* on Villager Type (shaded villages accept the project)

	Distance from agricultural land									
Distance from fishery	(a) No project	0	1	2	3	(b) L^P=2, P=1.35	0	1	2	3
	0	M	M	F	F	0	M	M	**F**	**F**
	1	M	M	F	F	1	M	M	**F**	**F**
	2	M	M	F	F	2	M	M	F	F
	3	M	M	F	F	3	M	M	F	F
	(c) L^P =2, P=1.5	0	1	2	3	(d) L^P =2, P=1.7	0	1	2	3
	0	**M**	M	**F**	**F**	0	**M**	**M**	**F**	**F**
	1	M	M	**F**	**F**	1	**M**	**M**	**F**	**F**
	2	M	M	**F**	**F**	2	**M**	M	**F**	**F**
	3	M	M	**F**	**F**	3	M	**M**	**F**	**F**

Figure 3a. Returns to Village Labour and Total Fish Catch

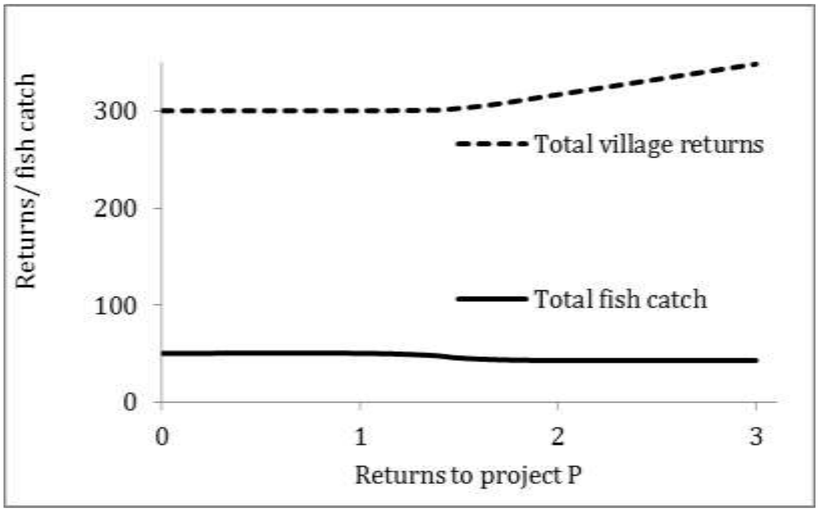
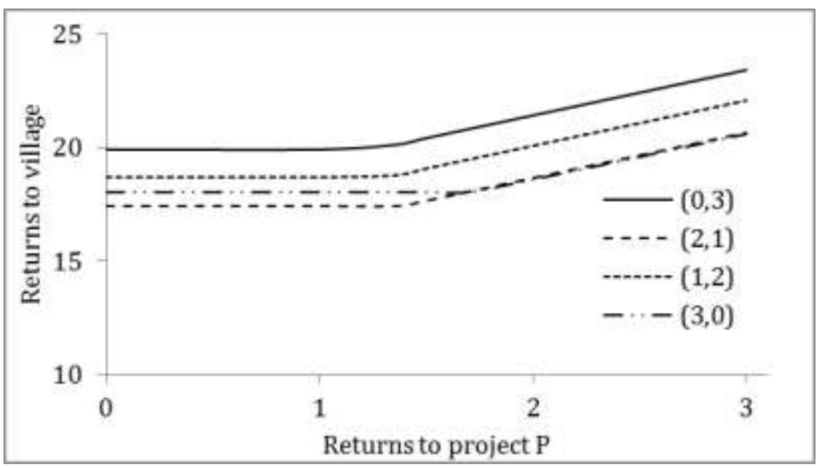


Figure 3b. Returns to Four Selected Villages as a Function of L^P



When gear exchange is combined with both enforcement and a livelihood project, the pattern of which villages accept and which reject the offer changes again. The villages that are Agriculture Only when there is enforcement and gear exchange are the only villages which also accept a low-returns livelihood project (P=1.2)—because at the margin the returns to this project are better than to farming or to switching back into some fishing (Table 4c). The remaining villages react to the combined offer of gear and project by rejecting that offer because they receive higher returns from fishing illegally than from fishing legally but allocating labour to the low-returns project. This reaction holds for both Fish Only or Mixed villages. With a higher return project such that P=1.35, 13 of the villages accept the project, with four switching to Agriculture Only (Table 4d). This response to the gear/project intervention has a significant impact on reducing fish catch because all these villages use the gear and receive lower catches. However, three villages do not accept the interventions even with the more generous returns to the livelihood project. These three villages are all Fish Only, all are the furthest distance from agricultural land, and all continue to fish illegally. These villages only see costs imposed by the MPA—the probability of being caught and fined—and no benefits because they reject the technological and livelihood offers from the park management. This analysis highlights the interaction amongst incentive-creating interventions in determining village acceptance of those interventions and demonstrates that the villages with the highest returns to fishing relative to other labour uses require larger incentives to reduce their pressure on the fish resource.

Table 4. Gear Exchange Vombined with Enforcement and Livelihood Projects (shaded villages accept gear exchange/project)

	Distance from agricultural land									
Distance from fishery	(a) q=0.2, no gear exchange no project	0	1	2	3	(b) q=0.2 gear exchange No project	0	1	2	3
	0	M	M	M	F	0	M	M	**M**	**M**
	1	M	M	M	F	1	M	**M**	**M**	F
	2	M	M	M	F	2	**M**	**M**	**M**	F
	3	A	A	A	F	3	**A**	**A**	**A**	F
	(c) q=0.2 gear exchange L^P =2, P=1.2	0	1	2	3	(d) q=0.2 gear exchange L^P =2, P=1.35	0	1	2	3
	0	M	M	M	F	0	**M**	**M**	**M**	F
	1	M	M	M	F	1	**M**	**M**	**M**	F
	2	M	M	M	F	2	**M**	**M**	**M**	F
	3	**A**	**A**	**A**	F	3	**A**	**A**	**A**	**A**

Table 5. Impact of Interventions on Fish Catch for Selected Villages

	(0,3)	(1,2)	(2,1)	(3,0)	Total
Base case fish catch	3.98	3.74	2.51	2.51	12.74
Fish catch when q=0.2, gear exchange, no project	1.35	1.52	1.52	0.00	4.38
Fish catch when q=0.2, gear exchange, project P=1.2	3.98	2.14	2.14	0.00	8.25
Fish catch when q=0.2, gear exchange, project P=1.35	3.98	1.35	1.35	0.00	6.68

4. What Does the Model Predict for the Villages in MBREMP?

In the above section we have provided a very simple framework of rural households' decisions with respect to park interventions that can be sticks (enforcement), carrots (livelihood projects), or technology changing (gear exchange programs). We have shown that, depending on their access to fisheries and agricultural land, villagers are affected in different ways by these interventions that are not always intuitive, and conversely that the interventions have different impacts on fishing and therefore fish stocks depending on the spatial arrangement of villages. In this section we use the model and the findings as a lens to address the case of Mnazi Bay Ruvuma Estuary Marine Park (MBREMP) and in particular how the park managers used interventions that include enforcement, gear exchange, and non-marine non-agriculture livelihood projects such as bee keeping and fish ponds to achieve multiple aims of protecting the fishery, protect livelihoods, and gain cooperation from the villages in the MPA.

The villages in MBREMP fall into categories of being fishing-dependent and being agriculture-dependent based on their location with respect to the bay. By examining the model's results in Tables 2 through 4 we can predict the reaction of MBREMP villages to the marine park's enforcement, gear-exchange, and alternative livelihood projects. Although the modelling section characterizes a full matrix of village locations with respect to access to agricultural and fishing, MBREMP's villages do not have that variety of locations. We characterize the several villages with good access to the fishery but little access to agricultural land as falling into the $\left(T^F, T^A\right)$ category of (1,3); the villages with intermediate access to both agriculture and fishery as (2,2); and the agricultural villages far from the water as (3,1).

The model demonstrates that villages will respond to enforcement of gear restrictions with detection and fines by fishing less and undertaking more agricultural activities.

Enforcement alone reduces the relative value of fishing and so induces less fishing overall. In Figure 2a we see the total fish catch decline rapidly as the probability of being caught increases from 0.2 to 0.4. Additional enforcement effort has little impact on fish stocks because virtually all fishing is eliminated at this point. As in Table 3's entry for enforcement only for village (3,1), MBREMP villages that are distant from the fishery and close to agriculture may find that reduction in value enough to switch from a Mixed village to an Agriculture Only village. Villages at a more moderate distance from the fishery, as in (2,2), switch from Fish Only to Mixed villages by increasing their labour allocation to agriculture and reducing their fishing. Only if the relative value of fishing declines markedly will near-fishery villages respond to enforcement by switching to Mixed villages and villages at (1,3) remain Fish Only at moderate levels of enforcement.

In MBREMP villages, no villages reported undertaking the gear change in the enforcement-only stage, in line with our model, which implies that the costs of the new gear (a significant upfront investment for fisherfolk) and the lower fishing harvests with the new gear were more of a cost deterrent than continuing to fish with illegal gear and/or allocating more labour to agriculture. Considerable uncertainty about the level of enforcement and the promise of projects and gear-replacement programs may also have contributed to a reluctance to convert to the larger mesh nets that require significant upfront investments and therefore risk in the early stages of MPA implementation.

By 2007, MBREMP had implemented two gear-exchange programs and several livelihood projects including beekeeping and fish farming. We can use the model outcomes in Table 4 to predict the reaction of different MBREMP villages to the combination of enforcement and gear exchange. For the locations in Table 4 that represent the MBREMP villages, the model predicts that the fishing-distant villages (3,1) will continue to focus on agriculture, the intermediate villages (2,2) will remain mixed, and the fishing-local villages (1,3) will continue to focus on fishing in reaction to the gear exchange program. Only the intermediate and fishing-distant villages will cooperate with the gear exchange. Although the new gear implies lower fish harvests, because these villages spend less labour on fishing and therefore operate at a higher marginal value of fishing than Fish Only villages, the value of their labour in fishing with the new gear is higher than the value of the labour when they run the risk of paying a fine for illegal fishing. For villages located close (1,3) to fishing, the reduction in returns to labour from the new gear is not offset by the expected value of returns to illegal fishing and these villages do not accept the gear exchange in our framework (Table 4). Overall, the gear exchange paired with the enforcement induces no change in behaviour for villages that focus on fishing due to their proximity to that resource. The location and fishing-focus of Nalingu, Mnete[8], Msimbati, and Mkubiru permits their characterization as this type of (1,3) fishing-local villages. None of these villages participated in gear exchange in 2006 or 2007 (Table 1). Mngoji and Madimba might fall into a (2,2) category and both participated in the second round of gear exchange in 2007. Of the remaining villages, all fall into a (3,1) category for agricultural locations and all except Mahurunga and Kitunguli participated in a gear exchange by 2007.

By 2008, the MBREMP had offered and implemented several livelihood projects in addition to continuing gear-exchange and enforcement. The model predicts that, at low returns to the livelihood projects, only villages located at a significant distance from fishing will accept gear exchange combined with the livelihood projects (Table 4c, (3,1) for example). For other villages, the projects take labour time away from uses of time that offer higher returns. The net benefits from projects and the reduction in expected value from the enforcement are not large enough to induce these villagers to forego illegal fishing in exchange for the lower-yielding projects. In MBREMP, only Tangazo, a (3,1) category village, undertook a livelihood project in 2006. Further, those villages most involved in fishing, Nalingu, Mnete, Msimbati, and Mkubiru, were not involved in the phase 2a gear exchange in 2007, nor the dairy cattle and bee keeping initiatives, and only one village participated in a fish farming project in 2008. These data suggest that the park managers were not successful in offering, and having accepted, alternative livelihood activities to those most dependent on the marine park resources, as our model predicts.

The model demonstrates that moderate-access villages (2,2) accept gear exchange and projects only when the projects generate high returns, and fishing-focused villages do not accept projects at those levels of returns. The model predicts that higher-valued projects must be offered to fishing-focused villages in order to provide appropriate incentives for them to reduce their labour allocation to fishing. Our interviews revealed that the fishing associations in these non-cooperating villages have instructed their members to have nothing to do with the park management or NGOs working through the park. In particular, Nalingu villagers and MBREMP managers both report considerable conflict between park managers and fishermen. When we visited Nalingu, the village fishing committee welcomed us and discussed the situation calmly. After observing the projects in other villages, Nalingu villagers remain convinced that these projects do not come anywhere close to compensating them for the costs that the park has

[8] Mnete became a distinct village from Nalingu during the implementation of the MPA.

imposed. Although a project might improve their welfare relative to the current situation with enforcement of minimum mesh sizes, the villagers view the disparity between the burden imposed by the MPA restrictions and the project benefits as a reason not to cooperate with the MPA. Our model cannot predict such reactions but can identify villages like Nalingu as the least likely to cooperate with gear-exchanges and projects due to the profitability, relative to other villages, of fishing. In 2008, MBREMP sponsored an offshore fishing project that provided motorboats and gear to permit 4 villages, all four of the (1,3) category fishing villages (Nalingu, Mnete, Msimbati, and Mkubiru), to fish in the ocean, which these villages cannot undertake with their traditional equipment. This high-return project motivated all of these villages to participate, or accept, the project. The project provides the right incentives to induce the villages to allocate labour to ocean fishing, which reduces their labour allocation to fishing within the MBREMP.

4.1 Potential Impact of MBREMP Implementation on Fish Stocks and Sustainability

Most economic models propose a moratorium on fishing to allow depleted fish stocks to recover as quickly as possible. Because fishing villages in MBREMP and in many other developing countries sit in remote locations and contain few alternative livelihoods, a moratorium on the activity that provides nearly all income and protein to local people would impose considerable costs to those communities. MPAs in these settings may provide alternative livelihoods in conjunction with enforcement of a moratorium but incentives may remain for villagers to undertake illegal fishing, particularly in the most fish-dependent villages. Villagers may refuse the project because their labour is better spent fishing; they may accept the project but continue to fish illegally; they may accept the project and reduce their total fishing. Any illegal fishing that continues slows the regeneration of the depleted fish stocks. In general, an MPA's impact on fish stock recovery and long-run sustainability relies on how much the MPA's enforcement of access restrictions and incentives to harvest--based in part on alternative livelihood projects—reduce fish harvests. Here, we emphasize the short-run decisions of small-scale fishers who do not consider the impact of their decisions on the long run fish recovery to approximate harvesting decisions during the early stages of the MPA.

Our modelling framework predicts that for those villages most dependent on fishing—Fish Only villages, the MPA manager's initiatives, whether enforcement, projects, or gear exchange, have least impact on fish stocks. If a village remains Fish Only and rejects any of these interventions (in our model, villages (1,3) and (2,3)), then by definition villagers continue to put all their labour effort into fishing. Enforcement does not act as a deterrent, rather it simply reduces villagers' expected payoff from fishing without altering their catch (Table 5). This appears to be the case for villages such as Nalingu. Only when Fish Only villages switch types in response to enforcement does the enforcement act as a deterrent and do fish catches from such villages decrease. Similarly once a village has switched to Agriculture Only in response to enforcement, additional interventions such as projects being offered to these villages simply increase the villagers' labour income without affecting fish stocks (Table 4b and 4c, villages (3,0), (3,1) and (3,2)). Managers face a tradeoff between lower cost projects in agriculture-focused villages that generate small fishing reductions and higher cost projects in fishing-focused villages that have the potential to generate large fishing reductions. In MBREMP, none of the villages with ready access to the fishery have accepted livelihood projects, which implies that their fish harvests have not been limited. The projects in predominantly agricultural villages have generated incomes and goodwill but have had limited impact on fishing within the bay. Most impact on fish stocks therefore comes from interventions in villages with both agriculture and fishing where changes in enforcement affect villagers' marginal fishing decisions.

More villages have eventually cooperated with MBREMP's gear exchange programs than have accepted projects. The new, large-mesh nets leave juvenile fish to grow and procreate, thus regenerating the bay's fish stock. Some villagers have received or have motorboats with which they can fish in the ocean, thereby removing fishing pressure from the protected bay. But, most villagers report difficulties with capturing any fish in the bay with the new nets, which encourages them to buy or borrow fine mesh nets even following gear exchange. Park managers report that villagers have sold some of the new nets for a significant income boon, which further limits the impact of the gear on fish stocks.

With no ecological assessments of the recovery of MBREMP's fish stock undertaken so far, we cannot determine the impact of MBREMP's carrots and sticks on the fish stock and local biodiversity. Still, the model and the interviews with managers and villagers suggest that MBREMP's policies of gear exchange and livelihood projects have not altered fishing behaviour in several highly fishing-dependent villages sufficiently but have improved livelihoods and reduced fishing in mixed and agriculture-focused villages. Although the villagers are better off and there has been some reduction in fishing, better targeting could have had a larger impact on fishing stocks and more equitable distribution of interventions.

4.2 Policy Inconsistencies and Ongoing Conflict

The approach taken by the park managers has resulted in conflicts that were not anticipated when the park management plan was developed, despite a series of MPA-village meetings prior to MPA establishment, and despite a management team that appeared to us to be highly sensitised to the impact of the park on nearby villagers. In particular, five issues involve village incentives to cooperate and timing issues that we address here. Understanding these ongoing conflicts could inform future MPA policy in MBREMP and elsewhere and improve the likelihood of villagers complying with fishing regulations and reducing conflict between park managers and marine-dependent villagers.

First, early co-operators have struggled with the large-mesh nets and the lower fish harvests they provide, while many villagers continued to harvest illegally. The early co-operators express dissatisfaction that some groups that have continued with their illegal fishing activities are “rewarded” with new and legal fishing gear. The rolling nature of the gear exchange and projects creates some inequities over time in which early co-operators bear more costs of the MPA than late co-operators. Early co-operators, however, also tend to be the villages with the most to gain from cooperating in the short run. In addition, in MBREMP, reductions in funding in recent years implies that some villages who would like to cooperate and receive gear as the early co-operators did but do not have that opportunity.

Second, some villagers fish illegally but do not have the funds to purchase the legal gear and have missed the opportunity to exchange their gear, often because at the time they were offered the exchange they remained suspicious of MBREMP management. Although the probability of being caught harvesting illegally appears fairly low due to low levels of patrolling, the punishment for the illegal gear can be catastrophic for fishing households. Those punitive sanctions when caught often include the confiscation of their nets and boats, which makes future fishing virtually impossible. Although economic theory demonstrates that low detection rates combined with very large fines can effectively deter illegal activity at relatively low cost for the enforcing agency, villagers find that level of penalty to be out of proportion to the individual infractions. Villagers may respond to such sanctions by becoming less cooperative and disruptive out of anger.

Third, the park-sponsored projects all offer similar levels of value despite the diversity of the cost burdens the MPA imposes on villages, at least in the short run while fish stocks recover. Villages most dependent on the marine resources face the highest costs associated with complying with the MBREMP regulations, yet all villages were offered similar projects. Naturally, for those least dependent on the marine resources, the cost of accepting these projects and the park regulations concerning fishing technologies is low. But similarly the ecological benefits are low. If projects provide compensation for the costs imposed by the park, fishery-dependent villages should receive larger projects. Similarly, fishery-dependent villages require larger projects to create incentives for cooperation with fishing restrictions. Providing uniform projects across villages appears equitable on the surface but does not address unequal cost burdens across villages and does not induce the largest possible reductions in fish harvest.

Fourth, although our model views projects as operating at the village level, in reality most of the projects offer significant benefits to a relatively small group of villagers within each project village. The projects do not address the costs of complying with the MPA regulations for the remaining individual fishers and intra-village equity. Similarly, those projects do not create incentives to reduce fish harvests for the villagers who do not capture the project benefits. Fifth, the most common villager complaint concerns the difficulty of catching fish with the large mesh nets in the traditional fishing grounds within the bay. Many of the initial gear-exchanges replaced fine-mesh nets with 5 or 6 inch mesh nets, although regulations and late exchanges permit 3 inch mesh nets. With depleted fish stocks in the bay, these nets do not catch many fish. In the long run, when fish stocks have recovered, these nets will enable villagers to harvest larger and more valuable fish. But, the gear exchange and the enforcement of gear regulations do not address the need for villagers to catch fish during the transition to a large fish stock with large enough fish for the new nets to catch. It would have been better for the MPA management to offer the three inch nets early on when stocks were recovering, and as the stocks recover, encourage fisherfolk to switch to increasingly larger-mesh nets. A limited number of fisherfolk have received boats with large enough engines to use the new nets in the ocean but the remaining fisherfolk have no such alternative. The gear policy, then, poses significant difficulties during this transition period and villagers react by returning to illegal extraction, which further slows the fish stock recovery.

Fifth, because conservation managers now recognize the impact of protection policy on resource-dependent people and, in some cases, that livelihood projects can provide incentives for conservation, MPA managers face both conservation and rural development aspects to their managers. MBREMP officials report some frustration with this dual role because, although they see the importance and necessity of the livelihood projects, they are not trained as development experts. Yet, the rural poverty aspects of the MPA management loom large in MBREMP. One fisherman states that he undertook gear exchange but now uses his mosquito net to catch fish because he "can't protect against malaria when you are hungry." The framework here demonstrates that conservation policy requires an understanding of the setting in which resource-dependent people make decisions, which involves a significant component of rural development expertise in order to define and locate interventions to create conservation incentives without undermining rural welfare.

5. Conclusions

For Marine Protected Areas to contribute to marine ecosystem sustainability, MPA interventions must alter the tradeoffs local fishers face between different uses of their time enough for fishers to reduce their fishing harvests from the MPA. As in terrestrial parks, both our model and our observations in Mnzai Bay Ruvuma Estuary Marine Park (MBREMP) in Tanzania find that enforcement of access or gear restrictions discourages fishing by many fishers but has the smallest impact on the villages located closest to the fish resource who depend most on that resource and indeed at low to medium levels enforcement may have no impact on villagers whose only livelihood activity is fishing. Many protected areas in developing countries aim to offset the burdens of proximity to a park or to create additional incentives to limit fishing by offering livelihood projects to villagers. As with enforcement, the reaction to those projects varies across villages and again has the least impact on villages that focus on fishing. The simple model presented here, demonstrates that blanket MPA policies that do not take account of the heterogeneity in labour opportunities among villages (and therefore different dependencies on marine resources) impose very different costs and benefits on these different villages depending on their comparative advantages in fishing and agriculture. Although we abstract away from the dynamics of fish recovery here, we emphasize the early years of an MPA when villagers see no benefits from a recovered fish stock and, instead, bear the costs of limited harvesting to permit such recovery. Policies that do not target the primary fishing villages cannot generate as large an impact on marine stock recovery and sustainability as policies that create large enough incentives to reduce fish harvest by the most fishing-dependent villages. Moreover, because some villages cooperate and others do not, in the long run (though we do not model this in our paper) it is likely that even if total fishery extraction falls, non-cooperating villages may actually increase their extraction relative to the no intervention scenario.

Offering all villages the same package of gear exchange and livelihood projects might appear equitable, but that practice has caused conflict in MBREMP. Villages where fishing is least important have benefited from livelihood projects that improve villager incomes whilst shouldering few costs caused by marine enforcement or gear exchange programmes. Villages for whom fishing is particularly important often find that the livelihood projects do not come close to compensating them for the loss of legal access to the fishery. When the MBREMP management introduced their initial project interventions, “cooperative” villages were rewarded with projects and new gear. But their cooperation made sense because they had little to lose. The villages that continue to hold out against the park, refusing to accept livelihood projects, are those that are most harmed because they have little access to farming and have traditionally been predominantly fishing villages. With limited funds, it is tempting for the park management to maximise the number of cooperating villages by targeting those for whom the marine resources are least important. The number of villages cooperating can become an important metric of success because it is easier to measure than changes in fish stocks but it does not contain information about the impact on conservation and the move towards sustainability. Our paper suggests that marine protected areas such as that in Mnazi Bay need to look more closely at the spatial heterogeneity of costs imposed by the park and tailor their incentives and programmes to each village by taking account of the importance of the park resources for each village.

Our paper also has some general lessons for sustainability. In particular, whereas much of the literature on MPAs and fisheries focuses on sustainability of the fishery, our paper suggests that economic welfare also needs to be sustained, and policy makers must address the question of what this level of welfare might be, the implications for the MPA, and how villagers are affected differentially by the introduction of an MPA. Indeed, the interlinkage of the marine resource and economic welfare was emphasised in the Brundtland Commission (Brundtland and Khalid, 1987), yet little of the literature addresses this. Further, the pathway to the desired steady state fish stock is typically ignored in the literature. Yet in practice it is not clear how to get to that stock. In the early years of an MPA villagers get little if any benefits from the fishery. And if the MPA does not “work” in these early years, then it is unlikely that there will be any stock dynamics to worry about.

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