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Siting Marine Protected Areas with Area Targets

Protecting Rural Incomes, Fish Stocks, and Turtles in Costa Rica

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Abstract

With many countries seeking to increase the area conserved in marine protected areas (MPAs) to achieve the Convention on Biodiversity's protected area targets by 2020, we employ a bioeconomic model to determine which configurations of MPAs that meet area targets perform the best for secondary goals, including fishing yield, rural income, fish stocks, and sea turtle conservation. Motivated by observations in the northern Caribbean coast of Costa Rica, the paper models the reactions of fishers to various MPA policies and the impact of policies on income and yield in two different communities, in addition to the impact on fish stock and turtle populations. This region's tourism relies on wildlife observation, including sea turtle nesting, which links MPA conservation outcomes to on-shore wage opportunities such as turtle tour guides, but fishing activities can disrupt turtle reproduction. With artisanal fishers allocating time between fishing, traveling to fishing locations, and on-shore wage opportunities, the framework provides information about how the configuration of the MPA that achieves a target amount of MPA area affects turtle conservation and differentially affects two artisanal villages' fishers. Overall, this analysis moves beyond achieving area targets to determine how different MPA configurations affect subsets of fishers, fish stocks, and turtle conservation.

Keywords: marine protected areas; fish stocks; turtles; Costa Rica

JEL Codes: Q20

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1. Introduction

Many countries are in the process of dramatically expanding their marine protected area (MPA) systems to meet the conservation area requirements of an international agreement, the Convention on Biodiversity (CBD). Known collectively as the Aichi Targets, the CBD's Target 11 commits signatory governments to establishing protected areas covering 10% of coastal and marine areas that are integrated with the wider seascape by 2020 (CBD, 2011). Although these area-based targets drive general decisions, countries can consider the impact of the specific size, location, and enforcement of MPAs on various non-area-based goals of MPAs. Motivated by Costa Rica's discussions about expanding MPAs in the northern Caribbean, which involve impact on artisanal fishers in two fishing communities and on non-fishing benefits such as reef and turtle protection, this paper explores a stylized framework to determine the optimal combination of MPA locations and enforcement for achieving various goals, including fish yields, income, turtle reproduction, and fish stocks, given area-based targets. In addition, the analysis demonstrates the distribution of burdens and benefits from each MPA on deep sea and nearshore fishers and on people from two different coastal villages.

The fishery economics literature evaluates MPAs using spatial metapopulation models to explore the impact of a no-take reserve MPA on fishing outside the MPA, typically finding that fish dispersal from a perfectly protected MPA rarely offsets the loss from not fishing in the MPA (Carter 2003; Smith and Wilen, 2003; Sanchirico and Wilen 2001; Hannesson 1998). These models focus on fish dispersal, with less emphasis on the drivers of spatial fishing decisions or reactions to enforcement of MPAs. Yet, in addition to protecting biodiversity and ecosystem services, most MPAs explicitly recognize the role of the fish resource in livelihoods (Carter, 2003). Albers, et al. (2019) extends this literature to find the most effective MPAs for generating not just yield but rural income and fish stocks. Extensive surveys and stakeholder interviews identified central aspects of fisher decisions, MPA manager perspectives, and the institutional setting that informs that article's framework (Madrigal-Ballestero, et al. 2017). In response to stakeholder discussions, Albers, et al. (2019) incorporates villager labor allocation decisions across fishing and wage labor, heterogeneity in distance costs to fishing locations, and fishers' interactions in labor and location decisions, in addition to considering incomplete enforcement, which reflects serious budget constraints for patrols.

Albers, et al. (2019) focus on tradeoffs between the size, configuration, and enforcement levels in determining budget-constrained MPAs and on differences in MPA decisions facing different management goals. Several points are of particular relevance for this paper. First, that analysis demonstrates that increases in budget can lead to either larger or smaller optimal MPAs, based on how the enforcement budget, which is spread across all MPA sites, influences fisher location and fishing decisions. A large but poorly enforced MPA may not lead to changes in fisher decisions, while a small but highly enforced MPA can lead to large changes in fisher decisions that lead to larger conservation outcomes than in the large but unenforced MPA. The current discussion paper, however, focuses on the configuration of the MPA for a particular size of the MPA, which eliminates tradeoffs between size and enforcement levels. Second, as in enforcement research in terrestrial protected areas, lower levels of enforcement are required to deter extraction at distant rather than near-village locations (e.g., Albers, 2010). Third, the optimal MPAs that arise from several different manager goals – maximizing income, maximizing yield, maximizing avoided stock loss, and maximizing avoided stock loss within MPAs – vary widely across goals and across budgets. Fourth, Albers et al. (2019) demonstrate that higher conservation outcomes occur from MPA decisions that incorporate the response of fishers to the MPA. Fifth, the configuration of MPAs relies on the spatial/location decisions of fishers as a function of heterogeneity in distance costs and on the dispersal of fish across the marinescape and in reaction to system boundaries.

This paper uses the same spatial bioeconomic framework described and analyzed in related papers that emphasize fisher responses to MPAs and decisions about optimal MPAs (Albers, et al. 2015, 2019) but modifies that framework to depict a two-village setting and to characterize the MPA impact on turtle conservation, forming a stylized analysis of Costa Rica’s northern Caribbean coast. We model an existing MPA near one village (which mimics Tortuguero National Park and Tortuguero village) and an open-access fishery that borders on a distant MPA and is near a second village (Barra del Colorado). To reflect the fishers in this setting, the fishers in the model allocate their labor between fishing and work onshore for a wage. High tourist visitation rates to MPAs like Tortuguero National Park create onshore wage opportunities in the tourism industry that differ across villages (Madrigal-Ballestero, et al. 2017); here we use a higher wage in the village near the existing MPA than in the more distant MPA. Allocating labor to fishing implies making location decisions, which require consideration of distance costs and fishing gear types. In making these decisions, fishers from the two villages interact across space to generate a Nash equilibrium of locations and fishing effort. Because MPA managers may face low budgets that do not allow enforcement to deter fishing effort, fishers include the enforcement level in their fishing location and effort decisions. Fish disperse based on density and a tendency for adult fish to move offshore, but the neighboring MPA contains a high fish stock level, while the neighboring open access fishery contains a low fish stock level. Turtles spend much of their lifecycle at sea in deep waters but cross through shallow waters to lay their eggs on the beach. Although fishers do not target turtles for harvest, turtle populations at sea decline as a function of by-catch losses and long-run turtle populations decline when fishing boats and gear in migratory corridors disrupt turtles as they attempt to reach the beach. An MPA that restricts fishing thereby indirectly protects turtle populations.

Even in the case of a pure conservation motive for an MPA, such as turtle protection, the reaction of fishers determines the level of conservation and therefore must be included in the MPA decision. This analysis explicitly models fishers' location and labor allocation decisions from two different villages and across deep-sea and nearshore fishers in reaction to the MPA and its enforcement. Using that reaction to the MPA allows this model's managers to choose an MPA configuration that maximizes the post-policy outcomes of interest – yield, income, fish stock, and turtles – while meeting the area target. We undertake this analysis for a range of budget constraints to characterize the low-income country setting. Larger area targets for the same budget imply lower levels of enforcement throughout the MPA, which enters fishers' location and fishing labor decisions, and those decisions influence the other outcomes of interest. Using this stylized depiction of Costa Rica's Caribbean coast, we determine the optimal configuration of MPAs to meet a secondary goal for each of three area targets and discuss differences in those configurations in terms of differential impact on fishers from each village and of economic and ecological outcomes.

2. Model

2.1 Overview

We modify the modeling framework in Albers, et al. (2019) to create a spatial bio-economic model adapted to study the effect of expanding the MPA network in a stylized setting that reflects the northern Caribbean coast of Costa Rica. First, we define our stylized spatial setting as an IxJ grid (Figure 1). We consider two aspects in the biological part of the model: a fish metapopulation structure with density dispersal and the number of turtles that arrive on the beach, which determine the number of eggs laid. The economic part of the model includes two types of participants: villagers and one manager. We model two different villages located at opposite sides of the spatial settings (Figure 1). The villagers in both villages rely on income from onshore labor and fishing labor. Each villager considers other villagers' choices and chooses where and how much to fish to maximize his income. Finally, the manager considers both the fish dynamics and the villagers' choices to choose the site, size, and enforcement level to maximize its secondary goal (*i.e.*, yield, income, fish stock, turtle eggs) for an MPA area goal or target.

Figure 1: Spatial Setting

Village 1 Village 2

(1,1)	(1,2)	(1,3)
(2,1)	(2,2)	(2,3)

The spatial setting is a $\boldsymbol{I} \times \boldsymbol{J}$ grid with parameters $\boldsymbol{I} = \mathbf{2}$ and $\boldsymbol{J} = \mathbf{3}$, the number of sites is $\boldsymbol{I} \cdot \boldsymbol{J} = \mathbf{6}$, and there are two villages located onshore, one closest to the fishing site $(\mathbf{1}, \mathbf{1})$ and the other closest to the fishing site (1,3). Each site is identified by the ordered pair $(\boldsymbol{i}, \boldsymbol{j})$.

2.2 Fish Dynamics

In common with much of the marine economics literature, the biological and spatial setting is defined by a fish metapopulation structure on a marinescape represented by an $I \times J$ grid with density dispersal. Fish net growth, harvest, and dispersal over time change the fish stock in each site:

$$\boldsymbol{X_{t+1}} = \boldsymbol{X_t} + G(\boldsymbol{X_t}, \boldsymbol{K}) + \boldsymbol{D}\boldsymbol{X_t} - \boldsymbol{H_t} ,$$

where $\boldsymbol{X_t}$ is a $(I \cdot (J + 2)) \times 1$ vector of fish stocks over fishing sites $x_{i,j}$ at time t, $\boldsymbol{K}$ is a $(I \cdot J) \times 1$ vector of site carrying capacities, $\boldsymbol{D}$ is a $(I \cdot (J + 2)) \times (I \cdot (J + 2))$ dispersal matrix, and $\boldsymbol{H_t}$ is a $(I \cdot J) \times 1$ vector of all fishers' harvest from each site (i, j) at time t. The extra terms in the dispersal matrix and stock vector stem from having stocks in the existing MPA and open access regions that border the marinescape that is subject to these management decisions. Natural population net growth is represented with a logistic function $G(\boldsymbol{X_t}, \boldsymbol{K}) = g\boldsymbol{X_t}\left(1 - \frac{\boldsymbol{X_t}}{\boldsymbol{K}}\right)$ at each specific site, with g indicating the intrinsic net growth rate. The dispersal matrix $\boldsymbol{D}$ operationalizes the density dependent dispersal process as a linear function of fish stock densities of all sites. with net dispersal to lower density neighbors that share a boundary through rook contiguity (Sanchirico and Wilen 2001; Albers, et al., 2015). We adapted the dispersal to the context of the northern Caribbean coast in Costa Rica. On one edge of the marinescape, we account for the presence of an existing Marine Protected Area (*i.e.*, Tortuguero National Park) next to Village 1. An exogenous inflow of fish entering the marinescape through the two patches in the same column as Village 1 represents the fish moving away from the exogenous MPA to the marinescape. On the other edge of the marinescape, we account for the presence of an open access marine area next to Village 2. An exogenous outflow of fish leaving the marinescape through the two patches in the same column as Village 2 represents the fish moving towards the exogenous open access beyond the marinescape next to village 2. Our results hold in the steady state stock of fish, $\boldsymbol{X_{SS}}$, which occurs when $\boldsymbol{X_t} = \boldsymbol{X_{t+1}}$.

2.3 Villagers

We include two villages with two types of villagers. Village 1 fishers are constrained by fishing gear to fish in shallow waters (*i.e.*, first row of the spatial setting). Village 2 fishers can fish in both shallow water and deep water. Let N be the total number of villagers of any type. Each villager n has access to two sources of income – fishing and onshore labor for a wage – and their goal is to maximize income. To achieve this goal, the villager chooses where to fish, how much time to fish, and how much time to work onshore. In making this decision, each villager considers that the time spent working onshore (l_w), fishing in a given site ($l_{f(i,j)}$), and traveling in his boat from the village to the fishing site ($l_{d(i,j)}$) is constrained by their fixed total labor L:

$$L \leq l_w + l_{f(i,j)} + l_{d(i,j)}.$$

Fishing labor is used as an input to harvest fish following a standard harvest function that is shared by all villagers

$$h_{i,j} = l_{f(i,j)} x_{(i,j)} q_{(i,j)} \,,$$

where the harvest in a given site ($h_{(i,j)}$) depends on the amount of labor used ($l_{f(i,j)}$), the stock of fish ($x_{(i,j)}$), and the catchability coefficient ($q_{(i,j)}$). The harvest does not directly depend on the number of other fishers in the site (*i.e.*, no congestion costs), but it does indirectly depend on the other fishers' harvest in the site because the steady state stock is affected (*i.e.*, stock effect). The total harvest in a given site is the sum of all fishers' harvest in the site,

$$H_{i,j} = \sum_{k=1}^{N} h_{(i,j)}^{n} \,,$$

and dynamic stock effects occur through the impact of harvest on the state variable $x_{(i,j)}$ (an element of $\boldsymbol{X}$) in the steady state. Given this interaction of villagers' decisions in determining the steady state, a steady state spatial Nash equilibrium defines the fishing locations for each villager, in which each villager has no incentive to move to another site nor to alter their optimally chosen labor allocation. To simplify the problem, we constrain the villager to fish in only one site.

Finally, all villagers want to maximize their income, defined as

$$\max_{l_{f(i,j)}, l_w} \left[p h_{i,j} \left(1 - \phi_{(i,j)}\right) + w_v (l_w)^{\gamma} \right],$$

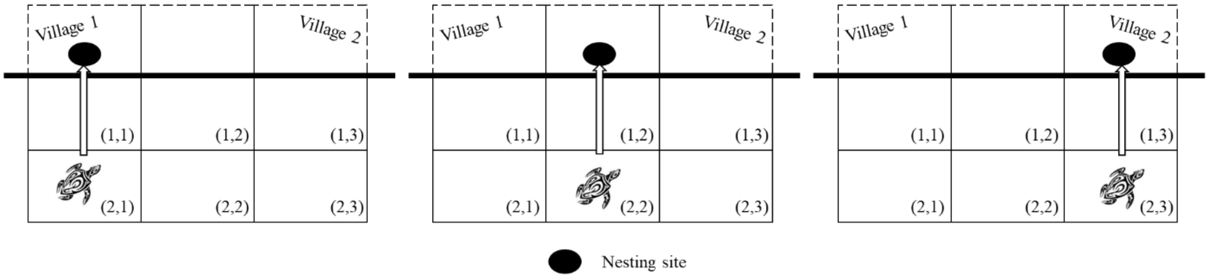
where p is the exogenous price of fish, w_v represents the onshore wage rate in village v, and $\gamma \in (0,1)$ allows for diminishing returns to onshore wage labor to reflect imperfect labor markets. The enforcement parameter $\phi_{(i,j)}$ is equal to 0 if the site (i, j) is not a protected area, and equal to $\phi \in [0,1]$ otherwise. The level of enforcement (ϕ) inside the protected area is chosen by the MPA manager and enters the fishers' objective function to reflect the probability that the fisher is caught while fishing illegally in a protected area. Complete enforcement, $\phi = 1$, implies that no illegal harvesting goes undetected; no enforcement, $\phi = 0$, implies that no illegal harvesting is detected; and incomplete enforcement, $\phi < 1$, reduces the expected fishing harvest in that location, which can deter some or all illegal harvesting.

2.4 Turtles

Sea turtles migrate, often thousands of miles, from foraging areas to breeding areas. Our model considers sea turtles during breeding and focuses on turtles with high nesting site fidelity, such as the Green Turtle (*Chelonia mydas*) (Lutz et al., 2002; Chapter 8). Once in their breeding areas, sea turtles lay several clutches of eggs during a season. The period between a successful nest and the next nesting attempt is called inter-nesting. Thus, the number of eggs laid in the coast depends on both the survival rate of the turtles during the inter-nesting and the probability of successful nesting.

Because we focus on sea turtles with high nesting site fidelity, we assume in our spatial setting that during the inter-nesting most turtles stay in the deep water (or the second row of the column) where they nest. We explore three cases (Figure 3): turtles nest near village 1 on the beach of column 1; turtles nest between the villages on the beach of column 2; and turtles nest near village 2 on the beach of column 3. In each case, we set the total population of turtles (i.e., adult female sea turtles that need to reach the beach to lay their eggs) to 100 and allow for 15% of the turtles to be distributed in the sites other than the site to which they demonstrate fidelity. When the nesting occurs near a village, we assign 10% of the turtles to the site in between villages and 5% to the site near the other village. When the nesting occurs between villages, we assign 7.5% to each site near a village.

Figure 3: Turtles' Location



We model the number of turtle eggs laid as the result of two steps. In the first step, turtles are exposed to bycatch and other threats by boats (Wyneken et al, 2013; Chapter 12). A percentage of sea turtles survive this bycatch during inter-nesting, which is a function of the number of boats in their inter-nesting location. Second, the surviving turtles must cross the shallow waters of the first row to get to the beach and lay their eggs, which occurs with a second probability of success. The probability depends on the number of boats they encounter as they move toward the beach because vessel strikes, fishing gear, lights, and even noise can disturb the turtles and prevent them from reaching the beach (Lutz & Musick, 1997; Chapter 15). Finally, we assume that all the turtles that make it to the coast to nest lay 460 eggs, which represents the egg laying rate of Green Turtles (Lutz & Musick, 1997; Chapter 3).

In step 1, the number of surviving turtles in column k is given by

$$s_k = t_k \left[1 - \frac{t_k \times b_{(2,k)}}{T \times B}\right],$$

where t_k is the number of turtles in column k, $b_{(2,k)}$ is the number of boats in the second row of column k, T is the total number of turtles, and B is the total number of boats.

In step 2, surviving turtles in column k, s_k, attempt to reach the beach to nest. The probability of success is $1 - \frac{b_{1,k}}{B}$ and the number of turtles that reach the coast to nest is

$$\left[1 - \frac{b_{1,k}}{B}\right] \times s_k .$$

Finally, the total number of eggs laid is the sum of the product of the number of turtles nesting in each column and the number of eggs laid per turtle (*i.e.*, 460 eggs).

2.5 Manager

The role of the manager is to set up the Marine Protected Area in the marinescape (*i.e.*, the $I \times J$ grid) by identifying the area target or constraint, choosing the location of the MPA (*i.e.*, specific cells in the grid to protect) from among the various configurations that meet the area target, and choosing the level of enforcement to impose (ϕ) in the MPA (here constant across the MPA). Following the optimal enforcement literature, enforcement is costly and represented in linear and additive form (Nostbakken, 2008; Milliman, 1986; Sutinen & Andersen, 1985). To simplify, we constrain the manager to exercise the same level of enforcement in the whole MPA (*i.e.,* the level of enforcement in all protected cells is ϕ). Although we consider unlimited budgets, to characterize the Costa Rica setting, we explore different levels of a limited budget, or budget constraint, that the manager faces for enforcement activities. As above, fisher location and labor decisions reflect their reaction to the MPA locations and enforcement levels, in addition to the actions of other villagers.

We focus on a manager whose goal is to achieve an area target for the protected area. Area targets are common at the country level, especially as countries aim to meet the Convention on Biodiversity's Aichi Target #11 of 10% of marine and coastal regions in protected status. Because our study region represents only a fraction of Costa Rica's marinescape, Costa Rica might address the countrywide Aichi Target by conserving all or a portion of this particular region; we consider several levels of area targets, including making the entire area an MPA. In a budget-constrained case, larger MPAs imply a lower level of enforcement because the budget is spread over larger areas (see Albers, et al. 2019 for details). For comparison, we explore four non-area based manager secondary goals: to maximize total fish yield (including legal and illegal harvest), to maximize total income (from fishing and non-fishing activities), to maximize the aggregate fish stock in the marinescape, and to maximize the number of eggs laid by sea turtles nesting on the beach. For each goal and each area target, the manager chooses the optimal location and enforcement level while considering the fishers' responses to the MPA and its own budget constraint.

2.6 Solution Method and Parameters

The model is not analytically tractable, and we solve it using numerical methods. Table 1 presents all parameters. We use a MATLAB program to solve for all the spatial Nash equilibria for the N identical fishers' site and labor allocation decisions in the long-run biological (*i.e.*, fish stock) steady state. We use Stata to analyze the data generated by the MATLAB program.

Table 1: Parameters

Description	Parameter	Value
No. of columns (moving along the coast)	J	2
No. of rows (moving out to sea)	I	3
Width of each column	–	4
Width of each row	–	3.5
Position of village 1 by column	–	1
Position of village 1 by row	–	0
Position of village 2 by column	–	3
Position of village 2 by row	–	0
Total number of villagers	N	12
Number of villagers in Village 1	–	5
Number of villagers in Village 2	–	7
Villagers in Village 1 constrained to shallow water	–	5
Villagers in Village 2 constrained to shallow water	–	0
Intrinsic growth rate	g	0.4
Dispersal coefficient (from Smith et al. 2009)	m	0.4
Price of fish	p	1
Wage rate for non-fishing labor in Village 1	w^1	0.7
Wage rate for non-fishing labor in Village 2	w^2	0.4
Wage parameter (opportunity cost of time)	γ	0.6
Total time available per person	L	24
Catchability coefficient	$q_{(i,j)}, \forall\, i, j$	0.007
Carrying capacity for each site	$K_{(i,j)}, \forall\, i, j$	94.5
Cost of $\phi = 1$ for one site	c	30

3. Results

3.1 Overview

Area targets can be achieved through many MPA configurations. In this analysis, we demonstrate how, for each of three area targets (33%, 50%, 100% of the area), a secondary goal can be used to select the specific configuration of the MPA to achieve both the area target and a high value for the secondary goal. We also describe the impact on a range of outcomes (yield, income, stock, turtles, and village-specific income and yield) for each of these choices. We find large differences across the secondary goals – income, yield, fish stock, and turtle populations – in terms of the configuration of the MPA.

3.2 Open Access (no MPA) Basecase

In the open access basecase, most (4.5)[1] fishers from village 1 choose to fish next to their village with only one fisher (on average, 0.5 fishers across multiple equilibria) choosing to fish nearshore between the villages (Figure 7, 0 budget column). Fishers from village 2 also focus on their nearshore location (2.8) but also spread out to all other locations except the nearshore in front of village 1. Without any MPA, this marinescape produces a fish stock of 273.7; total income of 75.7, with village 1 earning 32.7 and village 2 earning 42.9; and total yield of 67, of which village 1 harvests 26.1 and village 2 harvests 41.0. The number of eggs laid in the open access case depends on the initial location of the turtles. In the case in which turtles nest near village 1, the number of eggs laid is 29424 (Figure 4). In the case in which turtles nest between villages, the number of eggs is 36843, while in the case in which turtles nest near village 2, the number of eggs is 30799 (Figures 5 and 6). The difference between this no-policy outcome and the MPA-policy outcome reflects the policy impact.

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[1] Fractional fisher numbers reflect averages over multiple equilibria.

Figure 4: Turtle Eggs Outcome in Open Access when Nesting is Near Village 1

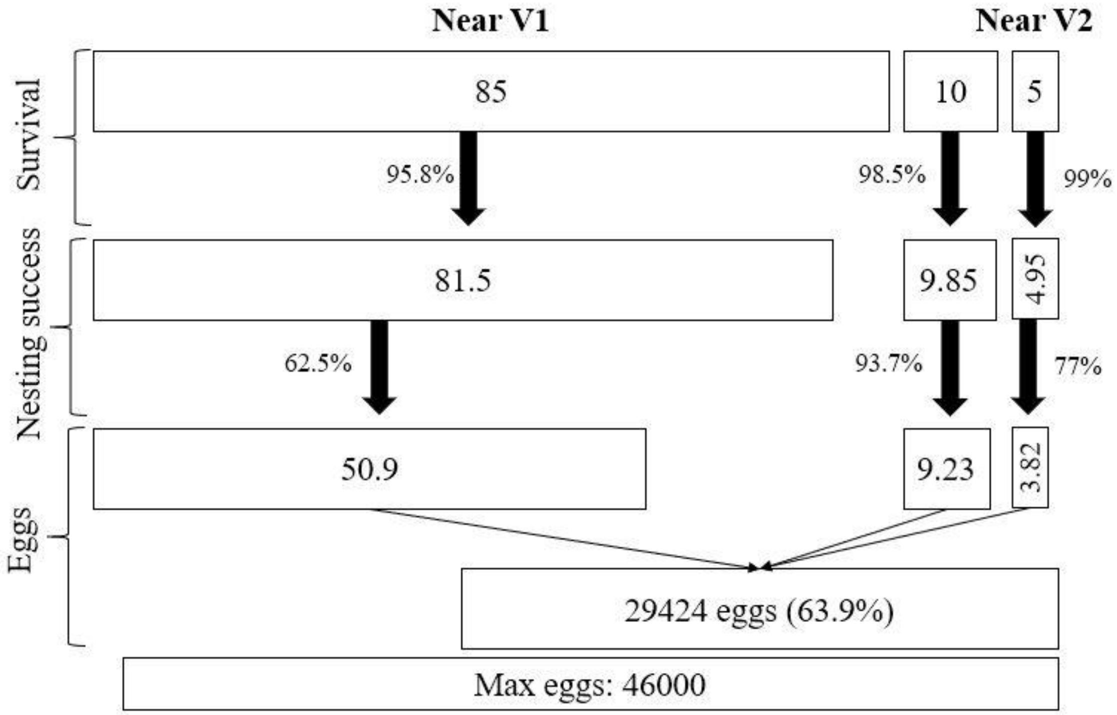


Figure 5: Turtle Eggs Outcome in Open Access when Nesting is Between Villages

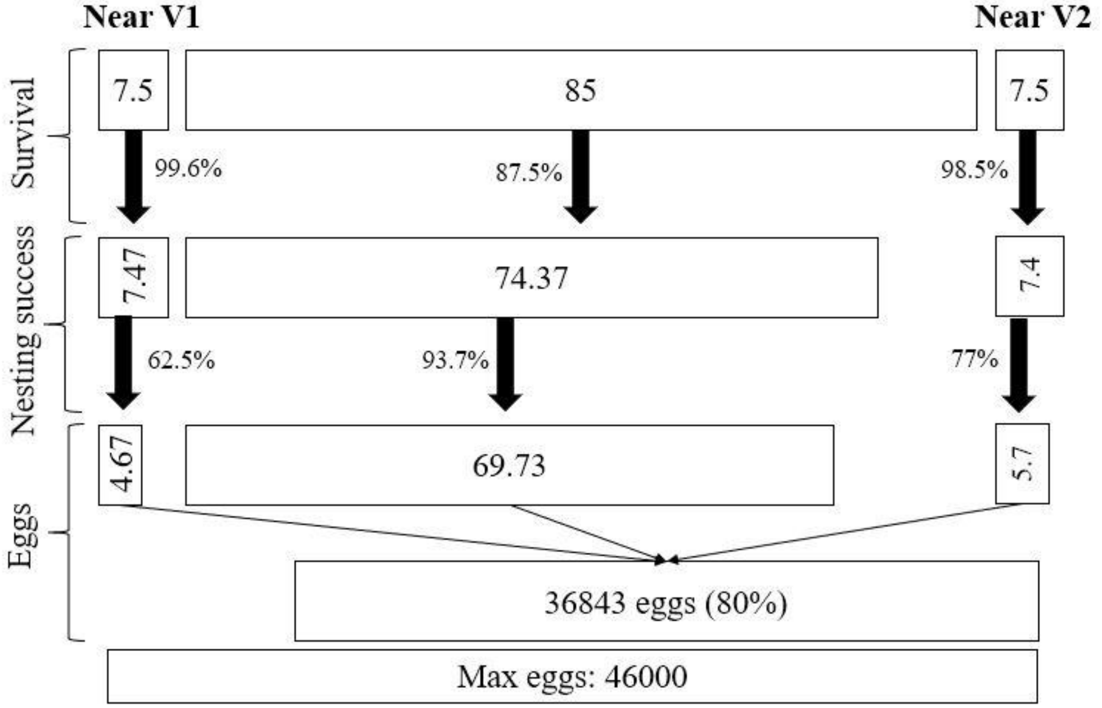
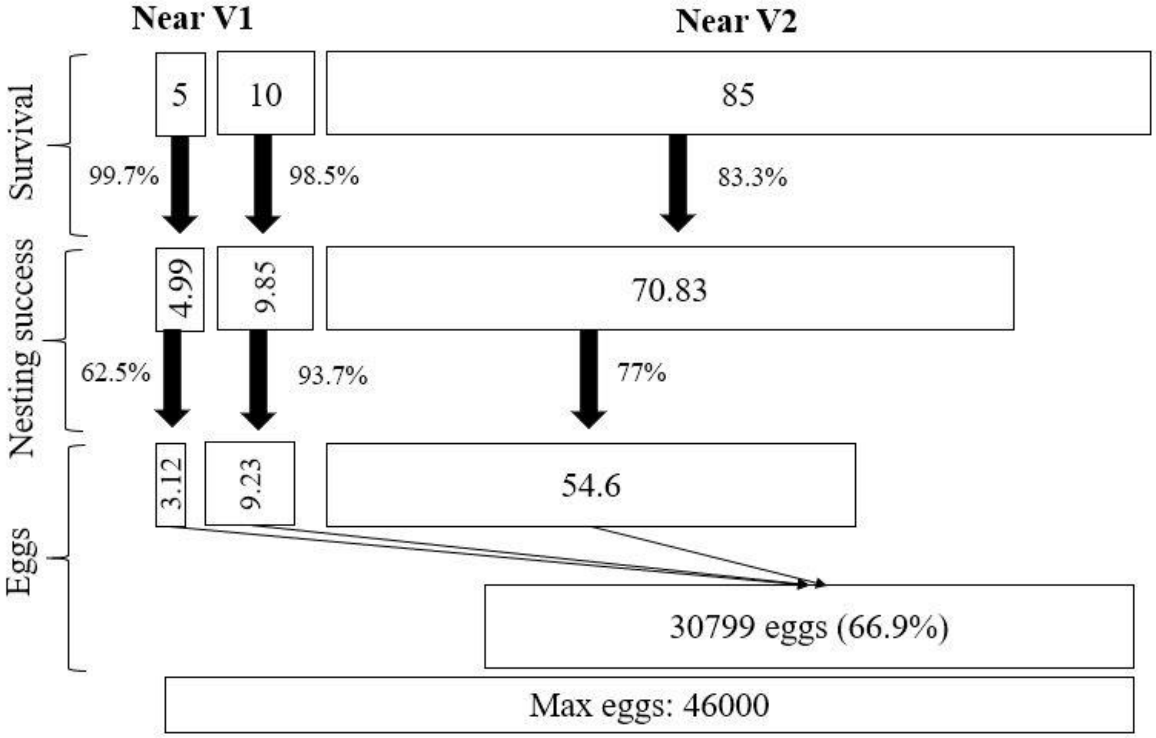


Figure 6: Turtle Eggs Outcome in Open Access when Nesting is Near Village 2



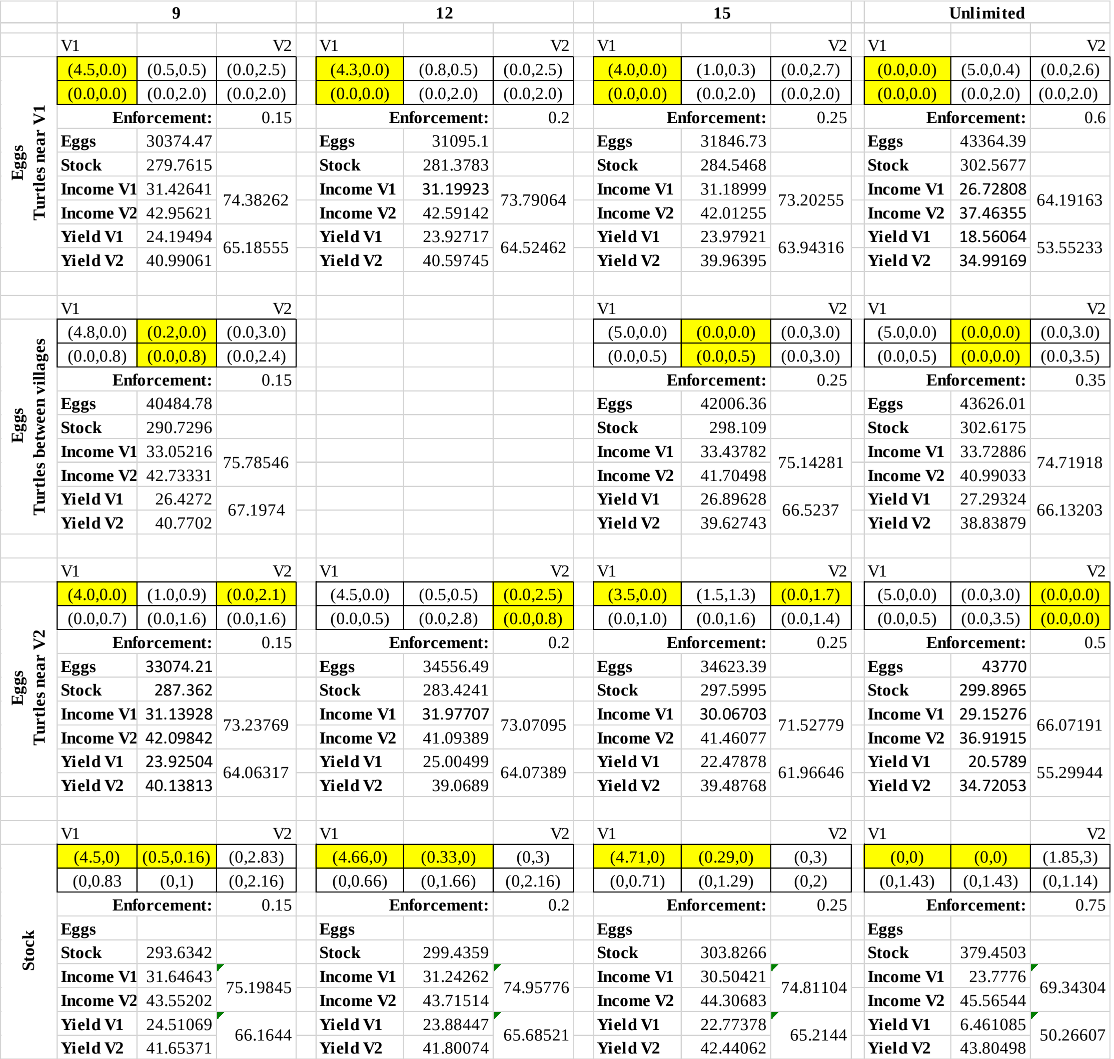
3.3 *Area Target of 33% of Marinescape*

The MPA manager achieves the 33% area target by selecting two sites for inclusion in the MPA, for which there are many possible combinations of sites and configurations of the MPA. The manager can select those sites to maximize a secondary objective, given the area target and a budget constraint (Figure 7). The optimal MPA configuration varies markedly across the choice of secondary goal and budget, and each choice has a differential impact on fishers in the two towns.

Figure 7: Area Target 33%: Optimal MPAs for each Secondary Goal and Fishers' Responses (Part 1)

	0 (open access)			3			6		
	V1		V2	V1		V2	V1		V2
Eggs **Turtles near V1**	(4.5,0.0)	(0.5,0.3)	(0.0,2.8)	(4.1,0.0)	(0.9,0.3)	(0.0,2.7)	(4.0,0.0)	(1.0,0.0)	(0.0,3.0)
	(0.0,0.5)	(0.0,1.5)	(0.0,2.0)	(0.0,0.7)	(0.0,1.1)	(0.0,2.1)	(0.0,0.8)	(0.0,1.6)	(0.0,1.6)
					Enforcement:	0.05		**Enforcement:**	0.1
	Eggs	29423.89		**Eggs**	29953.65		**Eggs**	30190.88	
	Stock	273.6981		**Stock**	279.4312		**Stock**	280.1609	
	Income V1	32.74719	75.65438	**Income V1**	32.73632	74.95003	**Income V1**	32.47229	74.69435
	Income V2	42.90719		**Income V2**	42.2137		**Income V2**	42.22206	
	Yield V1	26.08213	67.03736	**Yield V1**	26.15593	66.37726	**Yield V1**	25.81526	66.04816
	Yield V2	40.95523		**Yield V2**	40.22133		**Yield V2**	40.2329	
	V1		V2	V1		V2	V1		V2
Eggs **Turtles between villages**	(4.5,0.0)	(0.5,0.3)	(0.0,2.8)	(4.8,0.0)	(0.2,0.5)	(0.0,2.5)	(4.6,0.0)	(0.4,0.2)	(0.0,2.8)
	(0.0,0.5)	(0.0,1.5)	(0.0,2.0)	(0.0,0.5)	(0.0,1.3)	(0.0,2.2)	(0.0,1.0)	(0.0,0.6)	(0.0,2.4)
					Enforcement:	0.05		**Enforcement:**	0.1
	Eggs	36842.81		**Eggs**	37565.27		**Eggs**	39997.93	
	Stock	273.6981		**Stock**	279.9264		**Stock**	287.2406	
	Income V1	32.74719	75.65438	**Income V1**	32.22054	75.75475	**Income V1**	32.88273	75.91579
	Income V2	42.90719		**Income V2**	43.53421		**Income V2**	43.03307	
	Yield V1	26.08213	67.03736	**Yield V1**	25.2446	66.87492	**Yield V1**	26.22748	67.33812
	Yield V2	40.95523		**Yield V2**	41.63032		**Yield V2**	41.11064	
	V1		V2	V1		V2	V1		V2
Eggs **Turtles near V2**	(4.5,0.0)	(0.5,0.3)	(0.0,2.8)	(4.7,0.0)	(0.3,0.7)	(0.0,2.3)	(5.0,0.0)	(0.0,0.0)	(0.0,3.0)
	(0.0,0.5)	(0.0,1.5)	(0.0,2.0)	(0.0,0.5)	(0.0,1.5)	(0.0,2.0)	(0.0,0.0)	(0.0,3.0)	(0.0,1.0)
					Enforcement:	0.05		**Enforcement:**	0.1
	Eggs	30799.38		**Eggs**	31804.46		**Eggs**	32687.62	
	Stock	273.6981		**Stock**	277.0567		**Stock**	272.4319	
	Income V1	32.74719	75.65438	**Income V1**	32.09116	75.31231	**Income V1**	32.2428	75.27978
	Income V2	42.90719		**Income V2**	43.22114		**Income V2**	43.03697	
	Yield V1	26.08213	67.03736	**Yield V1**	25.11123	66.43396	**Yield V1**	25.24609	66.34731
	Yield V2	40.95523		**Yield V2**	41.32273		**Yield V2**	41.10122	
	V1		V2	V1		V2	V1		V2
Stock	(4.5,0.0)	(0.5,0.3)	(0.0,2.8)	(4.5,0)	(0.5,0.75)	(0,2.25)	(4.6,0)	(0.4,0.2)	(0,2.8)
	(0.0,0.5)	(0.0,1.5)	(0.0,2.0)	(0,0.625)	(0,1.125)	(0,2.25)	(0,1)	(0,0.6)	(0,2.4)
					Enforcement:	0.05		**Enforcement:**	0.1
	Eggs			**Eggs**			**Eggs**		
	Stock	273.6981		**Stock**	280.7886		**Stock**	287.2406	
	Income V1	32.74719	75.65438	**Income V1**	31.90399	75.00242	**Income V1**	32.88273	75.9158
	Income V2	42.90719		**Income V2**	43.09843		**Income V2**	43.03307	
	Yield V1	26.08213	67.03736	**Yield V1**	24.87696	66.06594	**Yield V1**	26.22748	67.33812
	Yield V2	40.95523		**Yield V2**	41.18898		**Yield V2**	41.11064	
	V1		V2	V1		V2	V1		V2
Income	(4.5,0.0)	(0.5,0.3)	(0.0,2.8)	(5,0)	(0,0.33)	(0,2.66)	(4.6,0)	(0.4,0.2)	(0,2.8)
	(0.0,0.5)	(0.0,1.5)	(0.0,2.0)	(0,0.33)	(0,1.66)	(0,2)	(0,1)	(0,0.6)	(0,2.4)
					Enforcement:	0.05		**Enforcement:**	0.1
	Eggs			**Eggs**			**Eggs**		
	Stock	273.6981		**Stock**	278.8041		**Stock**	287.2406	
	Income V1	32.74719	75.65438	**Income V1**	32.23354	75.81651	**Income V1**	32.88273	75.9158
	Income V2	42.90719		**Income V2**	43.58297		**Income V2**	43.03307	
	Yield V1	26.08213	67.03736	**Yield V1**	25.22811	66.91249	**Yield V1**	26.22748	67.33812
	Yield V2	40.95523		**Yield V2**	41.68438		**Yield V2**	41.11064	
	V1		V2	V1		V2	V1		V2
Yield	(4.5,0.0)	(0.5,0.3)	(0.0,2.8)	(4.75,0)	(0.25,0.25)	(0,2.75)	(4.6,0)	(0.4,0.2)	(0,2.8)
	(0.0,0.5)	(0.0,1.5)	(0.0,2.0)	(0,0.5)	(0,1.5)	(0,2)	(0,1)	(0,0.6)	(0,2.4)
					Enforcement:	0.05		**Enforcement:**	0.1
	Stock	273.6981		**Stock**	278.9861		**Stock**	287.2406	
	Income V1	32.74719	75.65438	**Income V1**	32.52935	75.79114	**Income V1**	32.88273	75.9158
	Income V2	42.90719		**Income V2**	43.26179		**Income V2**	43.03307	
	Yield V1	26.08213	67.03736	**Yield V1**	25.70695	67.04758	**Yield V1**	26.22748	67.33812
	Yield V2	40.95523		**Yield V2**	41.34063		**Yield V2**	41.11064	

Figure 7: Area Target 33%: Optimal MPAs for each Secondary Goal and Fishers' Responses (Part 2)



	9			12			15			Unlimited		
Eggs Turtles near V1	V1		V2	V1		V2	V1		V2	V1		V2
	(4.5,0.0)	(0.5,0.5)	(0.0,2.5)	(4.3,0.0)	(0.8,0.5)	(0.0,2.5)	(4.0,0.0)	(1.0,0.3)	(0.0,2.7)	(0.0,0.0)	(5.0,0.4)	(0.0,2.6)
	(0.0,0.0)	(0.0,2.0)	(0.0,2.0)	(0.0,0.0)	(0.0,2.0)	(0.0,2.0)	(0.0,0.0)	(0.0,2.0)	(0.0,2.0)	(0.0,0.0)	(0.0,2.0)	(0.0,2.0)
	Enforcement:		0.15	**Enforcement:**		0.2	**Enforcement:**		0.25	**Enforcement:**		0.6
	Eggs	30374.47		**Eggs**	31095.1		**Eggs**	31846.73		**Eggs**	43364.39	
	Stock	279.7615		**Stock**	281.3783		**Stock**	284.5468		**Stock**	302.5677	
	Income V1	31.42641	74.38262	**Income V1**	31.19923	73.79064	**Income V1**	31.18999	73.20255	**Income V1**	26.72808	64.19163
	Income V2	42.95621		**Income V2**	42.59142		**Income V2**	42.01255		**Income V2**	37.46355	
	Yield V1	24.19494	65.18555	**Yield V1**	23.92717	64.52462	**Yield V1**	23.97921	63.94316	**Yield V1**	18.56064	53.55233
	Yield V2	40.99061		**Yield V2**	40.59745		**Yield V2**	39.96395		**Yield V2**	34.99169	
Eggs Turtles between villages	V1		V2				V1		V2	V1		V2
	(4.8,0.0)	(0.2,0.0)	(0.0,3.0)				(5.0,0.0)	(0.0,0.0)	(0.0,3.0)	(5.0,0.0)	(0.0,0.0)	(0.0,3.0)
	(0.0,0.8)	(0.0,0.8)	(0.0,2.4)				(0.0,0.5)	(0.0,0.5)	(0.0,3.0)	(0.0,0.5)	(0.0,0.0)	(0.0,3.5)
	Enforcement:		0.15				**Enforcement:**		0.25	**Enforcement:**		0.35
	Eggs	40484.78					**Eggs**	42006.36		**Eggs**	43626.01	
	Stock	290.7296					**Stock**	298.109		**Stock**	302.6175	
	Income V1	33.05216	75.78546				**Income V1**	33.43782	75.14281	**Income V1**	33.72886	74.71918
	Income V2	42.73331					**Income V2**	41.70498		**Income V2**	40.99033	
	Yield V1	26.4272	67.1974				**Yield V1**	26.89628	66.5237	**Yield V1**	27.29324	66.13203
	Yield V2	40.7702					**Yield V2**	39.62743		**Yield V2**	38.83879	
Eggs Turtles near V2	V1		V2	V1		V2	V1		V2	V1		V2
	(4.0,0.0)	(1.0,0.9)	(0.0,2.1)	(4.5,0.0)	(0.5,0.5)	(0.0,2.5)	(3.5,0.0)	(1.5,1.3)	(0.0,1.7)	(5.0,0.0)	(0.0,3.0)	(0.0,0.0)
	(0.0,0.7)	(0.0,1.6)	(0.0,1.6)	(0.0,0.5)	(0.0,2.8)	(0.0,0.8)	(0.0,1.0)	(0.0,1.6)	(0.0,1.4)	(0.0,0.5)	(0.0,3.5)	(0.0,0.0)
	Enforcement:		0.15	**Enforcement:**		0.2	**Enforcement:**		0.25	**Enforcement:**		0.5
	Eggs	33074.21		**Eggs**	34556.49		**Eggs**	34623.39		**Eggs**	43770	
	Stock	287.362		**Stock**	283.4241		**Stock**	297.5995		**Stock**	299.8965	
	Income V1	31.13928	73.23769	**Income V1**	31.97707	73.07095	**Income V1**	30.06703	71.52779	**Income V1**	29.15276	66.07191
	Income V2	42.09842		**Income V2**	41.09389		**Income V2**	41.46077		**Income V2**	36.91915	
	Yield V1	23.92504	64.06317	**Yield V1**	25.00499	64.07389	**Yield V1**	22.47878	61.96646	**Yield V1**	20.5789	55.29944
	Yield V2	40.13813		**Yield V2**	39.0689		**Yield V2**	39.48768		**Yield V2**	34.72053	
Stock	V1		V2	V1		V2	V1		V2	V1		V2
	(4.5,0)	(0.5,0.16)	(0,2.83)	(4.66,0)	(0.33,0)	(0,3)	(4.71,0)	(0.29,0)	(0,3)	(0,0)	(0,0)	(1.85,3)
	(0,0.83	(0,1)	(0,2.16)	(0,0.66)	(0,1.66)	(0,2.16)	(0,0.71)	(0,1.29)	(0,2)	(0,1.43)	(0,1.43)	(0,1.14)
	Enforcement:		0.15	**Enforcement:**		0.2	**Enforcement:**		0.25	**Enforcement:**		0.75
	Eggs			**Eggs**			**Eggs**			**Eggs**		
	Stock	293.6342		**Stock**	299.4359		**Stock**	303.8266		**Stock**	379.4503	
	Income V1	31.64643	75.19845	**Income V1**	31.24262	74.95776	**Income V1**	30.50421	74.81104	**Income V1**	23.7776	69.34304
	Income V2	43.55202		**Income V2**	43.71514		**Income V2**	44.30683		**Income V2**	45.56544	
	Yield V1	24.51069	66.1644	**Yield V1**	23.88447	65.68521	**Yield V1**	22.77378	65.2144	**Yield V1**	6.461085	50.26607
	Yield V2	41.65371		**Yield V2**	41.80074		**Yield V2**	42.44062		**Yield V2**	43.80498	

To maximize income with a two-unit MPA for a low budget of "3", the optimal MPA occurs in the center column nearshore and the village 1 column offshore, with enough enforcement to improve total income, fish stock, and the number of turtle eggs (all 3 nesting cases) as compared to the open access case. Still, the yield and income for village 1 decline with this MPA while the yield and income for village 2 increase, as compared to open access. This MPA configuration alters fishing locations by the village 1 fishers in minor ways but induces village 2 fishers to locate in the offshore center to take advantage of dispersal from the MPA there. At higher budgets, the secondary goal of income-maximizing creates an MPA corridor in the center column, which also increases fish stock and the number of turtle eggs (in all cases) as compared to the base case. With this configuration and budget, both villages see an increase in income and yield. Maximizing income as a secondary goal occurs at a level of incomplete enforcement, which means that not all the budget is spent at budgets above “6” (see also Albers, et al. 2019). Maximizing this secondary goal therefore limits the potential ecological gains from the MPA in its emphasis on income and the area target.

With a secondary goal of maximizing yield, the optimal MPA that meets this area target occurs in the center column at all budgets, which induces increases in stock, number of turtle eggs, income and yield at low budgets, although yield and income decline for village 1. At higher budgets, all outcomes improve, including village 1’s yield and income, but budgets beyond “6” are not spent on enforcement because higher levels of enforcement decrease yield.

Maximizing the secondary goal of fish stock, for the 2-unit MPA and for the low budget, requires an MPA unit nearshore near both village 1 and village 2. That configuration reduces total income and yield to fishers but village 2 fishers see increases in both yield and income due to fishing in dispersed-to locations. The increase in fishing in column 1 and nearshore in column 2 reduces the number of turtle eggs when the nesting site is in column 1 and 2, as compared to the open access case. At higher budgets, the MPA configuration changes to include the offshore center column instead of nearshore at both villages, which leads to increases in income and yield for both villages, increased number of eggs (except when turtles nest in column 3), and the highest fish stock possible with 2 MPA units and a moderate enforcement budget. Budgets equal to and higher than 9 shift the MPA configuration to focus on the nearshore village 1 and center locations, with enforcement high enough to reduce total yield and income, while increasing fish stock and number of turtle eggs (except when turtles nest in column 3). The configuration and location of the MPA, however, differentially affects the two villages, with village 1 incurring lower yields and incomes at all budget levels with the MPA in the nearshore areas, in which all village 1 fishing occurs in open access.

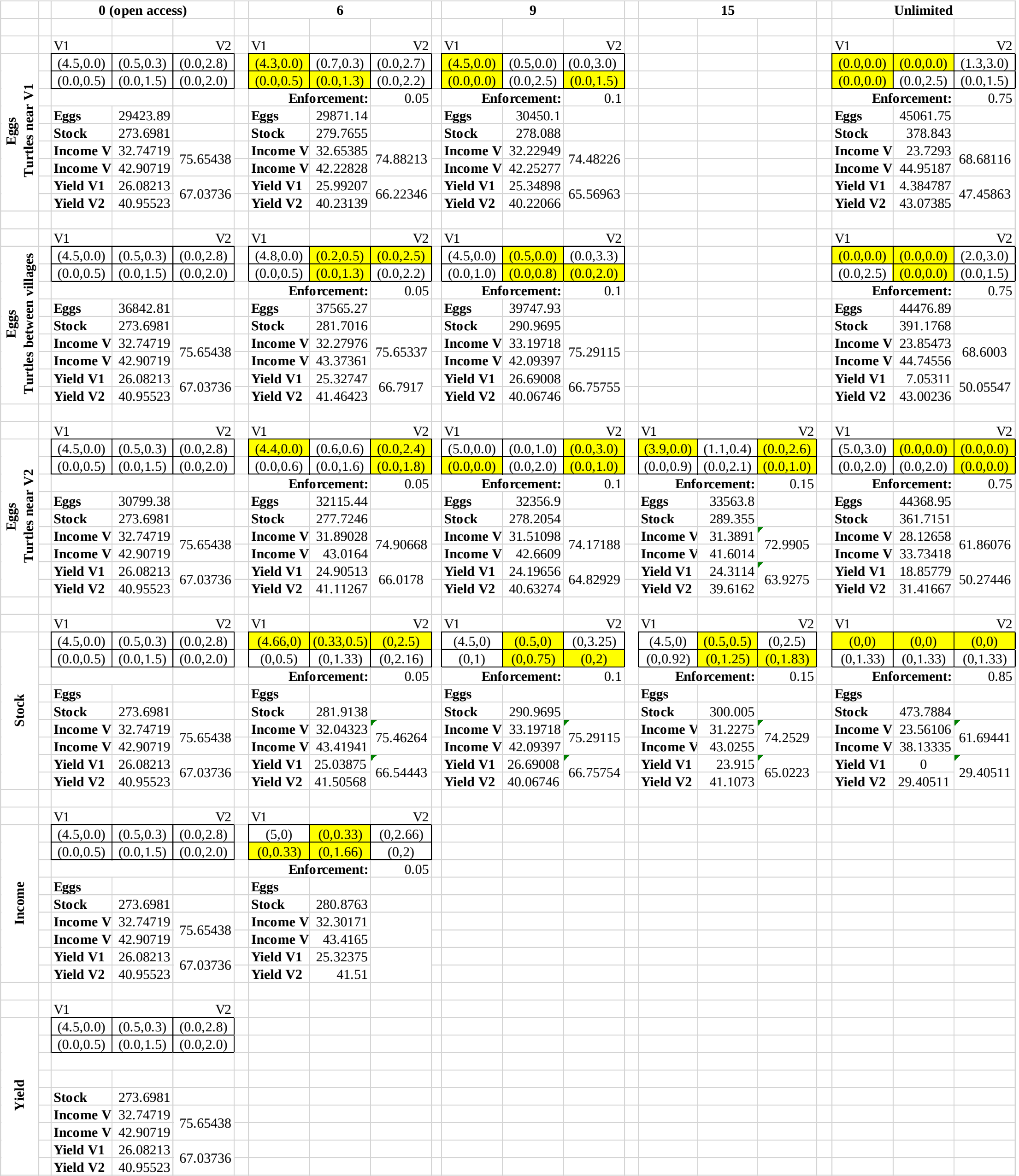
For a secondary goal of maximizing turtle populations while achieving the 33% area target, the MPA configuration again differs from those chosen for income and fish stocks as secondary goals. In addition, the MPA configuration also depends on the column in which most of the turtles nest. First, in the case of most turtles nesting near village 1, the optimal MPA at most levels of budget is to protect both sites in column 1. However, the manager needs a very high budget to deter fishing near the village. That is, the probability of turtles successfully getting to the beach to nest is low because there are many fishers near the beach due to the fish dispersing from the neighboring pre-existing MPA leading to high fish stocks. Fishers from village 2 are not affected much from the new MPA directly, but they are indirectly affected by the increased competition when the enforcement level is high enough to displace fishers from village 1 towards village 2. Second, when most turtles nest between villages, at the lowest budget level, the manager places the MPA nearshore in columns 2 and 3. Due to dispersal from the now-MPA and decreased fishing competition, village 2 fishers see increases in yield and income. With higher budget levels, the optimal MPA is to protect the entire second column. Even with unlimited budget, protecting the second column generates increases in both aggregate yield and income due to dispersal and reduced competition. While villagers from village 1 enjoy higher yield and income from fishing nearshore in column 1 (receiving dispersal from almost every side), villagers in village 2 have the exogenous open access on their border and are limited from fishing far from their village due to the MPA. Third, when turtles nest near village 2, the optimal MPA does not try to protect the whole of column 3 at low levels of enforcement budgets. Instead, the optimal MPA protects sites intended to induce fishers out of the column by inducing fish dispersal to increase stocks nearby. For example, at the lowest budget, the optimal MPA protects the site near shore in column 3 and the site offshore in column 2 to create nearby sites to which village 2 fishers can relocate in response to the MPA.

Only high budgets produce overlap between MPA configurations that provide the highest levels of two secondary goals, here turtle population and fish stock. At lower budgets, the MPA manager faces tradeoffs between secondary goals in choosing among the many MPA configurations that meet the 33% area target. Although the area targets themselves are not sensitive to the particular locations for the MPA, the configuration has differential impacts on all outcomes of interest – and between the two villages – due to the response of fishers to the MPA location and enforcement levels, which interacts with distance costs, offshore wage values, and the decisions of other fishers.

3.4 Area Target of 50% of Marinescape

Establishing an MPA to include half of the marinescape can occur with several configurations and, as with the one-third target, the highest valued MPA configurations differ across the secondary goals and their impact on other outcomes (Figure 8).

Figure 8: Area Target 50%: Optimal MPAs for each Secondary Goal and Fishers' Responses



	0 (open access)			6			9			15			Unlimited		
Eggs Turtles near V1	V1		V2	V1		V2	V1		V2				V1		V2
	(4.5,0.0)	(0.5,0.3)	(0.0,2.8)	(4.3,0.0)	(0.7,0.3)	(0.0,2.7)	(4.5,0.0)	(0.5,0.0)	(0.0,3.0)				(0.0,0.0)	(0.0,0.0)	(1.3,3.0)
	(0.0,0.5)	(0.0,1.5)	(0.0,2.0)	(0.0,0.5)	(0.0,1.3)	(0.0,2.2)	(0.0,0.0)	(0.0,2.5)	(0.0,1.5)				(0.0,0.0)	(0.0,2.5)	(0.0,1.5)
					Enforcement:	0.05		Enforcement:	0.1					Enforcement:	0.75
	Eggs	29423.89		Eggs	29871.14		Eggs	30450.1					Eggs	45061.75	
	Stock	273.6981		Stock	279.7655		Stock	278.088					Stock	378.843	
	Income V	32.74719	75.65438	Income V	32.65385	74.88213	Income V	32.22949	74.48226				Income V	23.7293	68.68116
	Income V	42.90719		Income V	42.22828		Income V	42.25277					Income V	44.95187	
	Yield V1	26.08213	67.03736	Yield V1	25.99207	66.22346	Yield V1	25.34898	65.56963				Yield V1	4.384787	47.45863
	Yield V2	40.95523		Yield V2	40.23139		Yield V2	40.22066					Yield V2	43.07385	
Eggs Turtles between villages	V1		V2	V1		V2	V1		V2				V1		V2
	(4.5,0.0)	(0.5,0.3)	(0.0,2.8)	(4.8,0.0)	(0.2,0.5)	(0.0,2.5)	(4.5,0.0)	(0.5,0.0)	(0.0,3.3)				(0.0,0.0)	(0.0,0.0)	(2.0,3.0)
	(0.0,0.5)	(0.0,1.5)	(0.0,2.0)	(0.0,0.5)	(0.0,1.3)	(0.0,2.2)	(0.0,1.0)	(0.0,0.8)	(0.0,2.0)				(0.0,2.5)	(0.0,0.0)	(0.0,1.5)
					Enforcement:	0.05		Enforcement:	0.1					Enforcement:	0.75
	Eggs	36842.81		Eggs	37565.27		Eggs	39747.93					Eggs	44476.89	
	Stock	273.6981		Stock	281.7016		Stock	290.9695					Stock	391.1768	
	Income V	32.74719	75.65438	Income V	32.27976	75.65337	Income V	33.19718	75.29115				Income V	23.85473	68.6003
	Income V	42.90719		Income V	43.37361		Income V	42.09397					Income V	44.74556	
	Yield V1	26.08213	67.03736	Yield V1	25.32747	66.7917	Yield V1	26.69008	66.75755				Yield V1	7.05311	50.05547
	Yield V2	40.95523		Yield V2	41.46423		Yield V2	40.06746					Yield V2	43.00236	
Eggs Turtles near V2	V1		V2	V1		V2	V1		V2	V1		V2	V1		V2
	(4.5,0.0)	(0.5,0.3)	(0.0,2.8)	(4.4,0.0)	(0.6,0.6)	(0.0,2.4)	(5.0,0.0)	(0.0,1.0)	(0.0,3.0)	(3.9,0.0)	(1.1,0.4)	(0.0,2.6)	(5.0,3.0)	(0.0,0.0)	(0.0,0.0)
	(0.0,0.5)	(0.0,1.5)	(0.0,2.0)	(0.0,0.6)	(0.0,1.6)	(0.0,1.8)	(0.0,0.0)	(0.0,2.0)	(0.0,1.0)	(0.0,0.9)	(0.0,2.1)	(0.0,1.0)	(0.0,2.0)	(0.0,2.0)	(0.0,0.0)
					Enforcement:	0.05		Enforcement:	0.1		Enforcement:	0.15		Enforcement:	0.75
	Eggs	30799.38		Eggs	32115.44		Eggs	32356.9		Eggs	33563.8		Eggs	44368.95	
	Stock	273.6981		Stock	277.7246		Stock	278.2054		Stock	289.355		Stock	361.7151	
	Income V	32.74719	75.65438	Income V	31.89028	74.90668	Income V	31.51098	74.17188	Income V	31.3891	72.9905	Income V	28.12658	61.86076
	Income V	42.90719		Income V	43.0164		Income V	42.6609		Income V	41.6014		Income V	33.73418	
	Yield V1	26.08213	67.03736	Yield V1	24.90513	66.0178	Yield V1	24.19656	64.82929	Yield V1	24.3114	63.9275	Yield V1	18.85779	50.27446
	Yield V2	40.95523		Yield V2	41.11267		Yield V2	40.63274		Yield V2	39.6162		Yield V2	31.41667	
Stock	V1		V2	V1		V2	V1		V2	V1		V2	V1		V2
	(4.5,0.0)	(0.5,0.3)	(0.0,2.8)	(4.66,0)	(0.33,0.5)	(0,2.5)	(4.5,0)	(0.5,0)	(0,3.25)	(4.5,0)	(0.5,0.5)	(0,2.5)	(0,0)	(0,0)	(0,0)
	(0.0,0.5)	(0.0,1.5)	(0.0,2.0)	(0,0.5)	(0,1.33)	(0,2.16)	(0,1)	(0,0.75)	(0,2)	(0,0.92)	(0,1.25)	(0,1.83)	(0,1.33)	(0,1.33)	(0,1.33)
					Enforcement:	0.05		Enforcement:	0.1		Enforcement:	0.15		Enforcement:	0.85
	Eggs			Eggs			Eggs			Eggs			Eggs		
	Stock	273.6981		Stock	281.9138		Stock	290.9695		Stock	300.005		Stock	473.7884	
	Income V	32.74719	75.65438	Income V	32.04323	75.46264	Income V	33.19718	75.29115	Income V	31.2275	74.2529	Income V	23.56106	61.69441
	Income V	42.90719		Income V	43.41941		Income V	42.09397		Income V	43.0255		Income V	38.13335	
	Yield V1	26.08213	67.03736	Yield V1	25.03875	66.54443	Yield V1	26.69008	66.75754	Yield V1	23.915	65.0223	Yield V1	0	29.40511
	Yield V2	40.95523		Yield V2	41.50568		Yield V2	40.06746		Yield V2	41.1073		Yield V2	29.40511	
Income	V1		V2	V1		V2									
	(4.5,0.0)	(0.5,0.3)	(0.0,2.8)	(5,0)	(0,0.33)	(0,2.66)									
	(0.0,0.5)	(0.0,1.5)	(0.0,2.0)	(0,0.33)	(0,1.66)	(0,2)									
					Enforcement:	0.05									
	Eggs			Eggs											
	Stock	273.6981		Stock	280.8763										
	Income V	32.74719	75.65438	Income V	32.30171										
	Income V	42.90719		Income V	43.4165										
	Yield V1	26.08213	67.03736	Yield V1	25.32375										
	Yield V2	40.95523		Yield V2	41.51										
Yield	V1		V2												
	(4.5,0.0)	(0.5,0.3)	(0.0,2.8)												
	(0.0,0.5)	(0.0,1.5)	(0.0,2.0)												
	Stock	273.6981													
	Income V	32.74719	75.65438												
	Income V	42.90719													
	Yield V1	26.08213	67.03736												
	Yield V2	40.95523													

A secondary goal of maximizing income with half of the marinescape covered comes from an MPA with the center column and the offshore near village 1 included. To maximize income, however, increasing budgets above "6" does not increase the optimal level of enforcement and therefore the impact on fish stock and turtle eggs remains unchanged. This

MPA configuration benefits village 2 fishers in terms of both income and yield, while village 1 faces declines despite the goal of maximizing total income. A secondary goal of maximizing yield with a 3-unit MPA occurs at zero enforcement, with no impact on any outcomes as compared to open access and no difference between the locations of unenforced MPA units.

In contrast, the secondary goal of maximizing fish stock results in an MPA along the entire nearshore coast at both low and high budgets. At a low budget of "6", this configuration decreases yield and income overall but provides higher yield and income to village 2 fishers because village 2 fishers have the appropriate gear to fish in the unprotected deep water. Intermediate budgets use an L shaped MPA with the center column and the offshore near village 2. This configuration flips the differential impact on fishers in the villages, with increases in yield and income for village 1 fishers and decreases for village 2 fishers. At high budgets, the maximum fish stock follows from an MPA in all nearshore locations. The complete deterrence of fishing along the coast produces declines in income and yield to both villages. The number of turtle eggs (in all cases) increase with increasing budgets for all max-fish stock configurations.

For all turtle location cases, the optimal MPA with unlimited budget is to protect the complete column where most turtles nest and a nearshore adjacent site (Figure 8). In the cases in which the nesting site is near a village, the adjacent nearshore MPA site occurs in the middle column. In the case in which the nesting site is between villages, the adjacent nearshore third site of the MPA protects the site nearest village 1 due to the high level of fishing there. In the cases of turtles located primarily in column 1 or 2, village 2 fisher incomes increase with the MPA, while village 1 fisher incomes decrease with the MPA in all turtle settings with unlimited enforcement budgets.

Even at low budgets, each turtle location case maintains two of the required three MPA sites in the column that contains turtles, but the location of the third MPA site differs with turtle location and with budget (Figure 8). In the case of turtles nesting near village 1, moderate budgets generate the highest turtle egg abundance by conserving the offshore site in village 2's column, while lower budgets move that third site to the center column. Despite the location of the third site offshore from village 2, that village's fishers receive more income with the moderate budget (budget "9") MPA than the lower budget MPA (budget "6"). Moderate budgets for the case of turtles between villages places the third MPA site offshore of village 2, while lower budgets place the third MPA site nearshore of village 2. At this lower budget ("6"), villager 2 fishers receive higher incomes than in the moderate budget case, while the opposite holds for village 1 fishers. For turtle fidelity to the third column, low budgets place the third site in nearshore of village 1; moderate budgets place it offshore of village 1; but higher budgets ("15") place it nearshore of village 1, with all budgets leading to complete deterrence of village 2 fishers in the third MPA site. In this turtle location setting, village 2 fisher income and yield improve with the low budget MPA but village 1 fishers, and village 2 fishers in all other budget settings, are worse off in terms of income and yields.

Tradeoffs among the secondary goals abound, with dramatic differences between the MPA configurations for each secondary goal at most budget levels. At this level of marinescape inclusion in the MPA, the MPA configurations for maximizing fish stock and turtles both reduce the income and yields generated by the marinescape, but that aggregate value masks the differential impact between the two villages that arises from the villages' heterogeneity in wage, gear, and proximity to an existing MPA. Village 2 fishers have the advantage of being able to fish in the offshore locations while village 1 fishers cannot, which enables village 2 fishers to respond to MPA locations by moving their fishing to locations that receive dispersal from the MPAs and to have no competition from village 1 fishers in offshore locations. However, fishers from village 1 benefit from the dispersal of fish from the neighboring exogenous MPA and a higher onshore wage. Even for same size MPAs, the configuration determines the differential impact on the two villages.

3.5 Area Target of 100% of Marinescape

Achieving the area target of 100% of the marinescape implies creating one large, 6-unit MPA (Figure 9). Still, the impact of the MPA on all outcomes derives from the level of enforcement applied.[2] Again, the yield maximum secondary goal is achieved with no enforcement, which generates no ecological or social benefits from the MPA. Similarly, maximizing income as a secondary goal also occurs at the point of no enforcement, in contrast to the benefits associated with low levels of enforcement when that enforcement occurs in a subset of the marinescape. For both the stock and turtle-maximizing secondary goals, both villages see reductions in yields and income for all budget levels. Still, because the MPA is so big, increases in budgets produce small increases in enforcement that do not increase fish stock and the number of turtle eggs until very high budgets.

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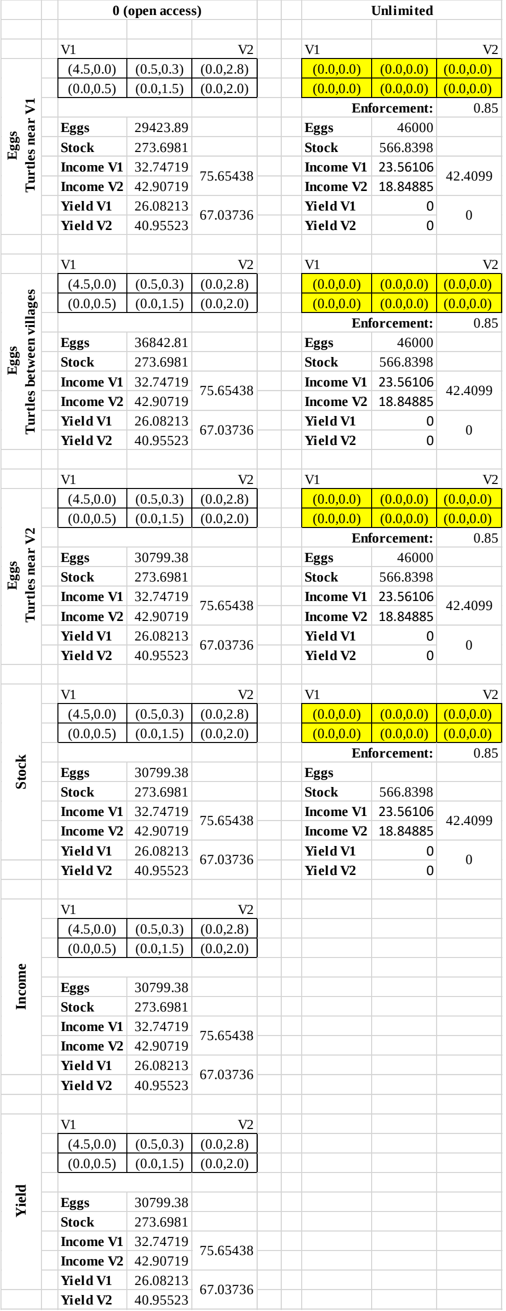
[2] The lowest level of enforcement considered here is a 0.05 probability of detection and punishment for a fisher in an MPA.

Figure 9: Area Target 100%: Optimal MPAs for each Secondary Goal and Fishers' Responses



	0 (open access)			Unlimited		
	V1		V2	V1		V2
Eggs Turtles near V1	(4.5,0.0)	(0.5,0.3)	(0.0,2.8)	(0.0,0.0)	(0.0,0.0)	(0.0,0.0)
	(0.0,0.5)	(0.0,1.5)	(0.0,2.0)	(0.0,0.0)	(0.0,0.0)	(0.0,0.0)
					Enforcement:	0.85
	Eggs	29423.89		Eggs	46000	
	Stock	273.6981		Stock	566.8398	
	Income V1	32.74719	75.65438	Income V1	23.56106	42.4099
	Income V2	42.90719		Income V2	18.84885	
	Yield V1	26.08213	67.03736	Yield V1	0	0
	Yield V2	40.95523		Yield V2	0	
	V1		V2	V1		V2
Eggs Turtles between villages	(4.5,0.0)	(0.5,0.3)	(0.0,2.8)	(0.0,0.0)	(0.0,0.0)	(0.0,0.0)
	(0.0,0.5)	(0.0,1.5)	(0.0,2.0)	(0.0,0.0)	(0.0,0.0)	(0.0,0.0)
					Enforcement:	0.85
	Eggs	36842.81		Eggs	46000	
	Stock	273.6981		Stock	566.8398	
	Income V1	32.74719	75.65438	Income V1	23.56106	42.4099
	Income V2	42.90719		Income V2	18.84885	
	Yield V1	26.08213	67.03736	Yield V1	0	0
	Yield V2	40.95523		Yield V2	0	
	V1		V2	V1		V2
Eggs Turtles near V2	(4.5,0.0)	(0.5,0.3)	(0.0,2.8)	(0.0,0.0)	(0.0,0.0)	(0.0,0.0)
	(0.0,0.5)	(0.0,1.5)	(0.0,2.0)	(0.0,0.0)	(0.0,0.0)	(0.0,0.0)
					Enforcement:	0.85
	Eggs	30799.38		Eggs	46000	
	Stock	273.6981		Stock	566.8398	
	Income V1	32.74719	75.65438	Income V1	23.56106	42.4099
	Income V2	42.90719		Income V2	18.84885	
	Yield V1	26.08213	67.03736	Yield V1	0	0
	Yield V2	40.95523		Yield V2	0	
Stock	V1		V2	V1		V2
	(4.5,0.0)	(0.5,0.3)	(0.0,2.8)	(0.0,0.0)	(0.0,0.0)	(0.0,0.0)
	(0.0,0.5)	(0.0,1.5)	(0.0,2.0)	(0.0,0.0)	(0.0,0.0)	(0.0,0.0)
					Enforcement:	0.85
	Eggs	30799.38		Eggs		
	Stock	273.6981		Stock	566.8398	
	Income V1	32.74719	75.65438	Income V1	23.56106	42.4099
	Income V2	42.90719		Income V2	18.84885	
	Yield V1	26.08213	67.03736	Yield V1	0	0
	Yield V2	40.95523		Yield V2	0	
Income	V1		V2			
	(4.5,0.0)	(0.5,0.3)	(0.0,2.8)			
	(0.0,0.5)	(0.0,1.5)	(0.0,2.0)			
	Eggs	30799.38				
	Stock	273.6981				
	Income V1	32.74719	75.65438			
	Income V2	42.90719				
	Yield V1	26.08213	67.03736			
	Yield V2	40.95523				
Yield	V1		V2			
	(4.5,0.0)	(0.5,0.3)	(0.0,2.8)			
	(0.0,0.5)	(0.0,1.5)	(0.0,2.0)			
	Eggs	30799.38				
	Stock	273.6981				
	Income V1	32.74719	75.65438			
	Income V2	42.90719				
	Yield V1	26.08213	67.03736			
	Yield V2	40.95523				

3.6 Comparing Outcomes Across Area Targets

In an analysis that selects all characteristics of the MPA, including size, location, and enforcement level, managers make tradeoffs between those aspects to maximize their goal for each budget level. In some cases, managers might generate higher values from smaller MPAs, especially when low budgets imply ineffectively low enforcement levels in the MPA (Albers, et al., 2019). Using area targets and then a secondary goal removes the ability to make such tradeoffs between size and enforcement levels.

In the scenarios considered here, higher incomes and higher yields result from the lowest area target, 33% of the marinescape, with low levels of enforcement. Although the 50% target MPAs have a small level of enforcement, the incomes generated are lower than those for the 33% area target. The 100% area target MPAs that maximize yield and income have no enforcement, which leads to open access level incomes and yields that are lower than those achieved by the 33% target MPAs. Smaller area targets generate higher yields and incomes. In contrast, the moderate sized area target (50%) provides higher incomes and yields to village 2 fishers than the low or high area target MPAs.

Although it is unsurprising that smaller MPAs lead to higher incomes and yields, the less intuitive result is that, for low budgets, the smaller area target MPAs generate higher stock and turtle levels than the higher area target MPAs. Having larger MPAs due to higher area targets implies that the enforcement budget gets spread over more area and creates a lower level of enforcement probabilities in all MPA locations, which corresponds to higher levels of fishing in all locations. In the examples explored here, no situations arise in which the increased area of the MPA offsets the lower level of the enforcement incentive to create higher ecological outcomes in terms of fish stocks and the number of turtle eggs. The unlimited budgets allow enough enforcement to lead to higher stocks and larger amounts of turtle eggs with larger target areas. For the low budget cases considered here, lower area targets provide the potential for higher levels of secondary targets, including fish stocks, turtle eggs, total income, and total yield, than the higher area targets can achieve.

Although constructing international conservation agreements and country goals around area targets proves simple, the goals of establishing and managing MPAs extend beyond meeting such targets, to include providing ecosystem services, including yield and income, and biodiversity protection. Although reaching the area targets and then addressing a secondary goal provides ecosystem services, achieving the secondary goals themselves without the size or area constraints allows for tradeoffs between size and enforcement at all budget levels. The ability to make those tradeoffs increases the ecological and economic outcomes from the resulting MPA and the economic efficiency of the MPA decisions, although sometimes at the cost of not achieving the area targets.

4. Conclusions

Our analysis provides several insights for systematic conservation planning in lower-income countries with limited budgets and where ecological systems and resource extraction interact. First, although larger MPAs more readily meet countrywide area targets, larger MPAs may provide lower levels of both economic and ecological outcomes than smaller MPAs. Limited budgets for enforcement must be spread over the larger MPA, which implies lower probabilities of detection and therefore less impact of the MPA on fishers' decisions about whether to harvest within the incompletely enforced MPA. Although conservation area targets intend to generate positive conservation gains, this analysis demonstrates that more ecological benefits can be created with smaller MPAs that allow enforcement spending to reduce or deter resource extraction – for example, in locations that turtles use during inter-nesting or in moving toward the beach for laying eggs.

Second, when achieving area targets but using secondary goals to determine the specific location of the reserve sites, the configuration of the MPA varies markedly across secondary goals, which provides further evidence that careful consideration of the actual locations chosen to achieve area targets is necessary to avoid negative consequences for other outcomes of importance. No one set of reserve sites that achieves an area target generates strong positive responses from all of the ecological and economic outcomes of import here. Similarly, much of the economics literature emphasizes the use of no-take reserves to generate off-site benefits to fishing from dispersal, but many conservation decisions focus instead on generating ecological conservation benefits. This analysis demonstrates that MPAs designed to provide ecological conservation differ from those designed to address economic goals. In addition, this paper demonstrates that MPA design differs across ecological goals, especially when those goals differ in their spatial production functions.

Third, the heterogeneity of the setting influences the optimal configuration of the MPA for a given MPA size or area target. Here, first, heterogeneity across villages in terms of gear and onshore wages influences the fishers' reactions to any MPA, thereby influencing the outcome of that MPA. Second, the heterogeneity of distance costs for both villages' fishers forms a large component of fishing site choices and fishing labor allocation decisions. Third, this region's southern border is an MPA that acts as a source of fish that disperse into the considered marinescape, while the northern border acts as a sink for fish to disperse out of the marinescape.

Those dispersal patterns inform MPA configuration decisions, particularly for fish stock secondary goals.

Fourth, despite the ecological goals, economic modeling of fishers' responses to MPA locations and enforcement provides information about the *ex post* conservation outcomes from an MPA. The location and labor allocation modeling of fishers' actions in response to MPA policies also identifies marinescape-wide impact, as fishers may "leak" their extraction to unprotected areas or may illegally harvest within MPAs, both of which can impact ecological outcomes. This spatially explicit model of fisher decisions enables managers to discern differential impacts across communities from all potential configurations and enforcement levels for MPAs. Even with purely area or purely ecological goals for siting and managing MPAs, evaluating the response of artisanal fishers to policy improves the economic efficiency of achieving those ecological goals.

Overall, the emphasis on establishing protected areas on particular amounts of area in many national policies and international agreements may not achieve high levels of conservation or other goals, even when the area target is met. This analysis demonstrates that, while many MPA configurations can meet an area target, particular configurations produce higher values for non-area outcomes of concern. Whether that secondary goal is economic – such as incomes, income distribution, or yield – or ecological – such as turtle nesting conservation or fish stocks – the configuration of the MPA interacts with fishing location and fishing labor allocation decisions, heterogeneous distance costs, and heterogeneous dispersal patterns to produce the post-MPA outcomes. Given those interactions, higher conservation or other outcomes arise from considering the spatial aspects of the ecological setting and fisher decisions when making MPA siting decisions within the context of achieving the area target.

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