Appendix 1 - Toy-model and scenarios

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TOY MODEL

This appendix provides further information on the toy-model and scenarios that was utilized to explore social-ecological tradeoffs in coastal Kenya.

Figure S1 is a system diagram of the variables and the connections of the toy-model utilized by participants to explore social-ecological tradeoffs. This particular version of the model emerged through a series of iterations and previous versions co-constructed with participants of the workshops referred to in the main paper. We summarize here the participatory process of model building.

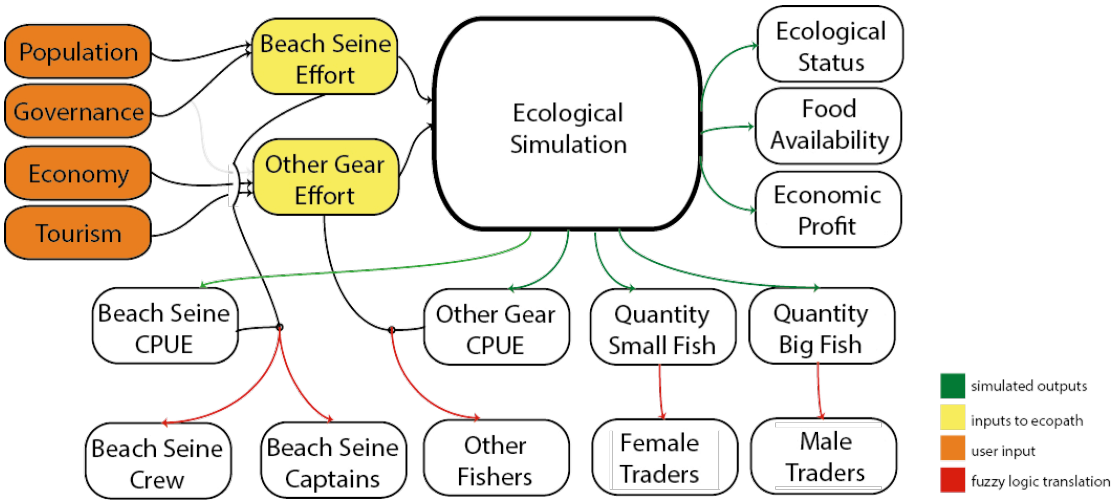

Figure S1. Final structure (after stakeholder's revisions) of the toy-model used to tradeoff analysis exercise.

Iterative participatory modelling

During the first workshop, through dialogue and discussions, participants developed a collective mental model of the social-ecological system in focus. Figure S2 is the direct transcription of this map that was created using post-its and drawings of arrows on a wall. A degree of uncertainty and a degree of overall importance was attributed to each linkage. These attributes were useful for the analysis and further "simplification" of the model.

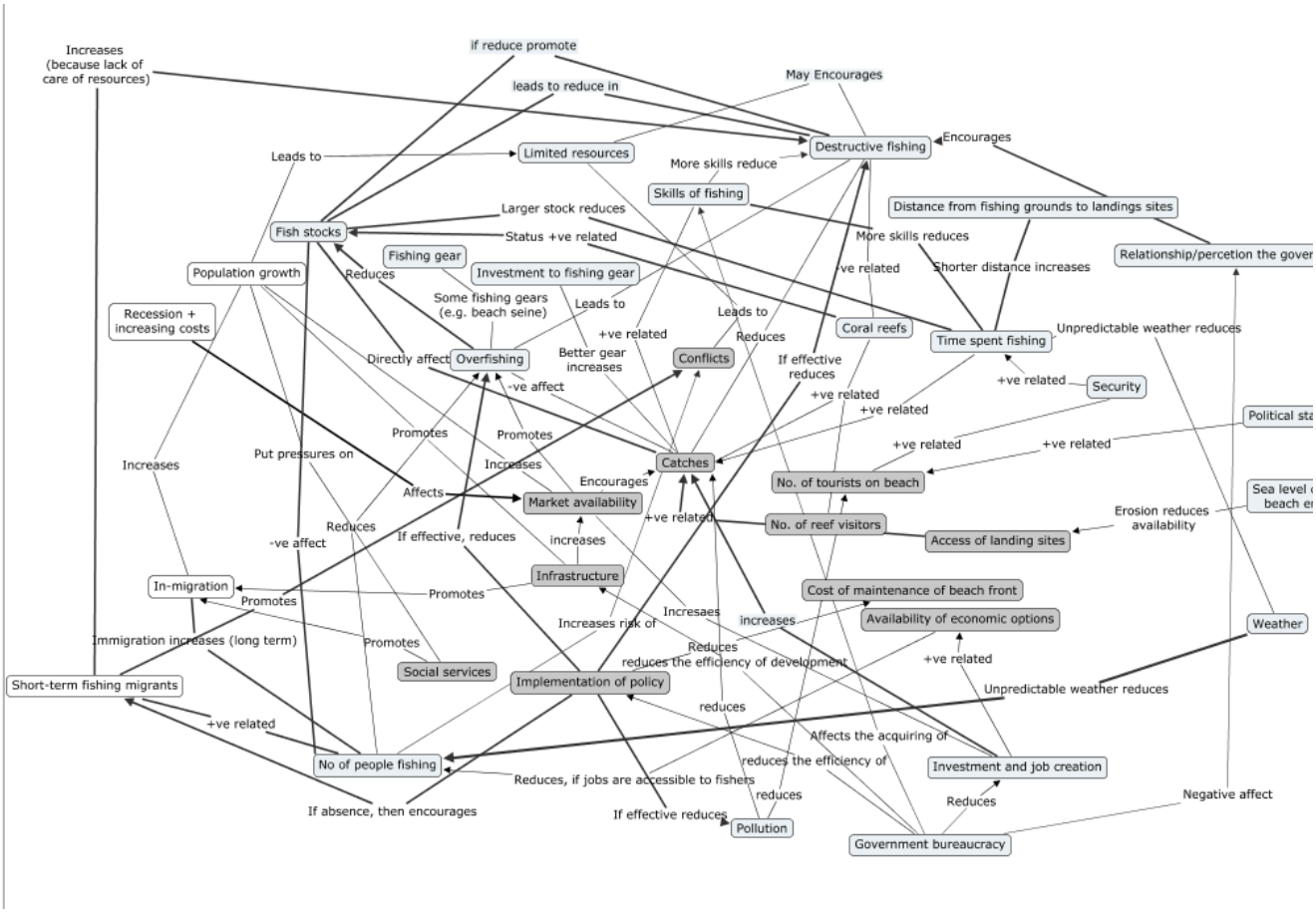

Figure S2. Workshop 1 collective model

In order to explore social-ecological tradeoffs the challenge now was to link this collective model (built by secondary stakeholders, i.e. those whose wellbeing is not directly affected by changes in ecosystems but that have influence in policy and management), to a ecological model of the fisheries (built in Ecopath) and to a thick account (based in focus groups) of what determines the wellbeing of different groups of primary stakeholders (those whose wellbeing is directly affected by changes in ecosystems).

The first step was to reduce to the number of variables of this collective model (Figure S2) to a smaller set of key dynamics. We translated the collective model into a network and applied network analysis to find the nodes that were more central. Figure S3 shows the collective model represented as a network. Each node represents a variable from the collective model. Each link's thickness were represented as the degree of importance that stakeholders associated to that particular linkage (Figure S3) and the degree of uncertainty (Figure S4).

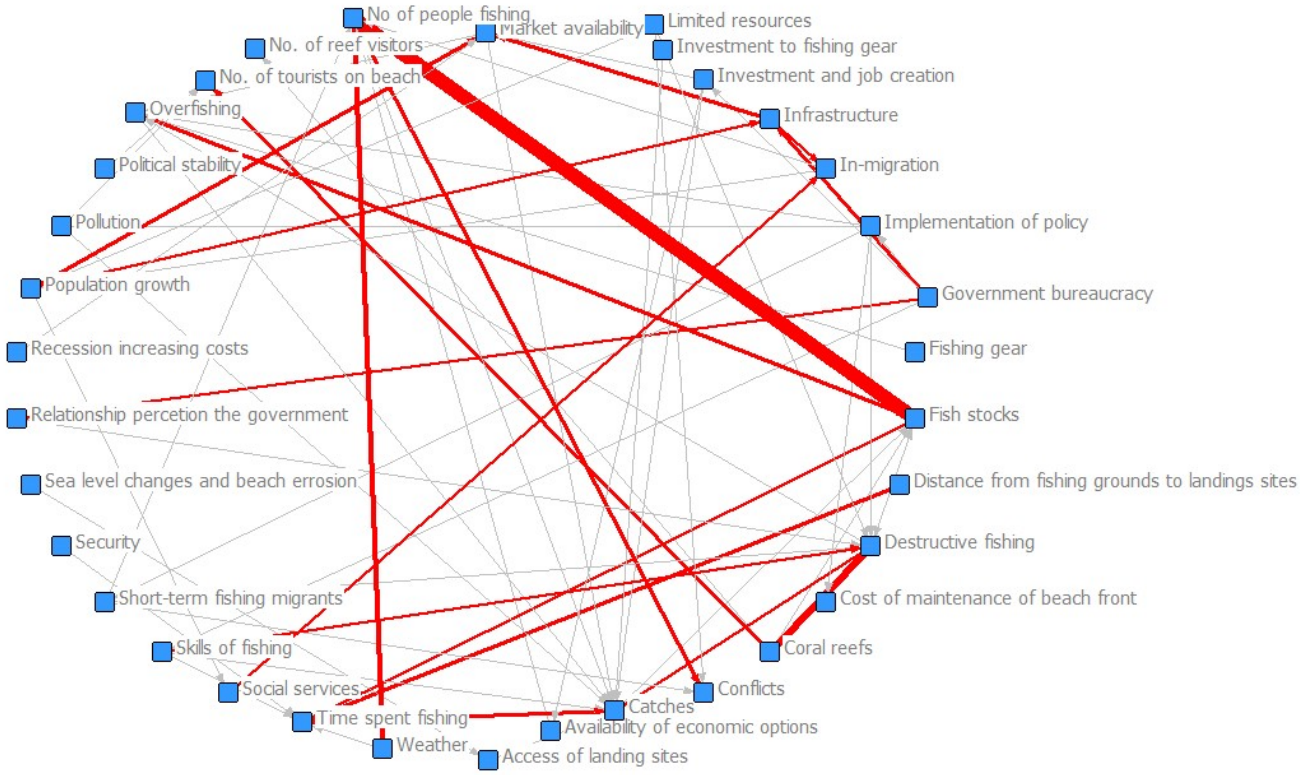

Figure S3. Collective model in a network representation. Links thickness represent degree of importance as identified by stakeholders.

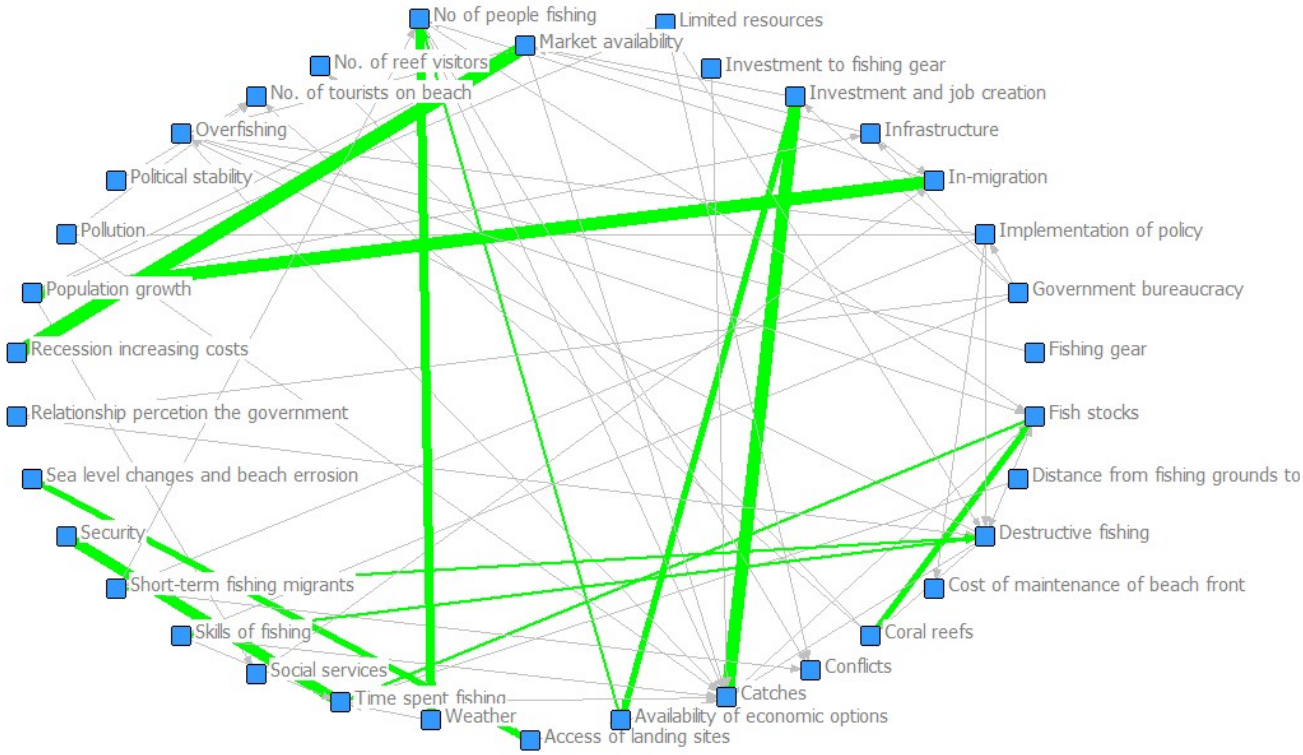

Figure S4. Links thickness represent degree of uncertainty.

Network analysis allows for the analysis of the directionality of linkages. In other words, if a statement says for instance that "weather affects number of people fishing", we can imagine a directed link going from weather to number of people fishing. In other words, weather is a source and number of people fishing a receiver. With this directional representation we then identified which nodes (components) were more frequently *sources* and which are more often *receivers*. In table 1, components are aligned in descendent order according to how important the component is as a source (measured by the number of outgoing links). Then in descendent order according to how important a component is a sink (measured by the number of incoming links). The most important sources can be thought as key drivers of the system. Based on this explorative analysis we created four broad categories (yellow columns in Table 1) that function as an umbrella for several other variables. The categories are governance, population, economy and tourism (Figure S5). Variables related to ecosystem functioning were categorized as Ecopath since their dynamics were incorporated in the detailed ecopath model.

Governance bureaucracy and Implementation of policy are the two components with higher number of links reaching out. This is an indicator that these two particular concepts are important drivers in the network since they affect many other variables (5 each). In the receiver side, the top ranking variables are related to fisheries. This means that fisheries can be seen as being heavily influenced by other factors.

Table S1. Degree analysis of the network

DRIVER Components	**Outdegree**	**Indegree**	**Category**
Government bureaucracy	5	1	Governance
Implementation of policy	5	0	Governance
Population growth	4	6	Population
Destructive fishing	4	0	ecopath
Coral reefs	3	4	ecopath
Investment and job creation	3	1	Economy
Short-term fishing migrants	3	1	Population
Skills of fishing	3	1	ecopath/Gov
No of people fishing	3	1	Population
Weather	2	5	ecopath
Limited resources	2	4	ecopath
RECEIVER Components	**Outdegree**	**Indegree**	**Category**
Catches	1	10	ecopath
Destructive fishing	4	6	ecopath
Fish stocks	2	5	ecopath
Time spent fishing	1	5	ecopath

No of people fishing	3	4	Population
Market availability	2	4	Economy
Overfishing	2	4	ecopath
Conflicts	0	3	population
No. of tourists on beach	0	3	Tourism
Infrastructure	2	2	governance
In-migration	1	2	Population

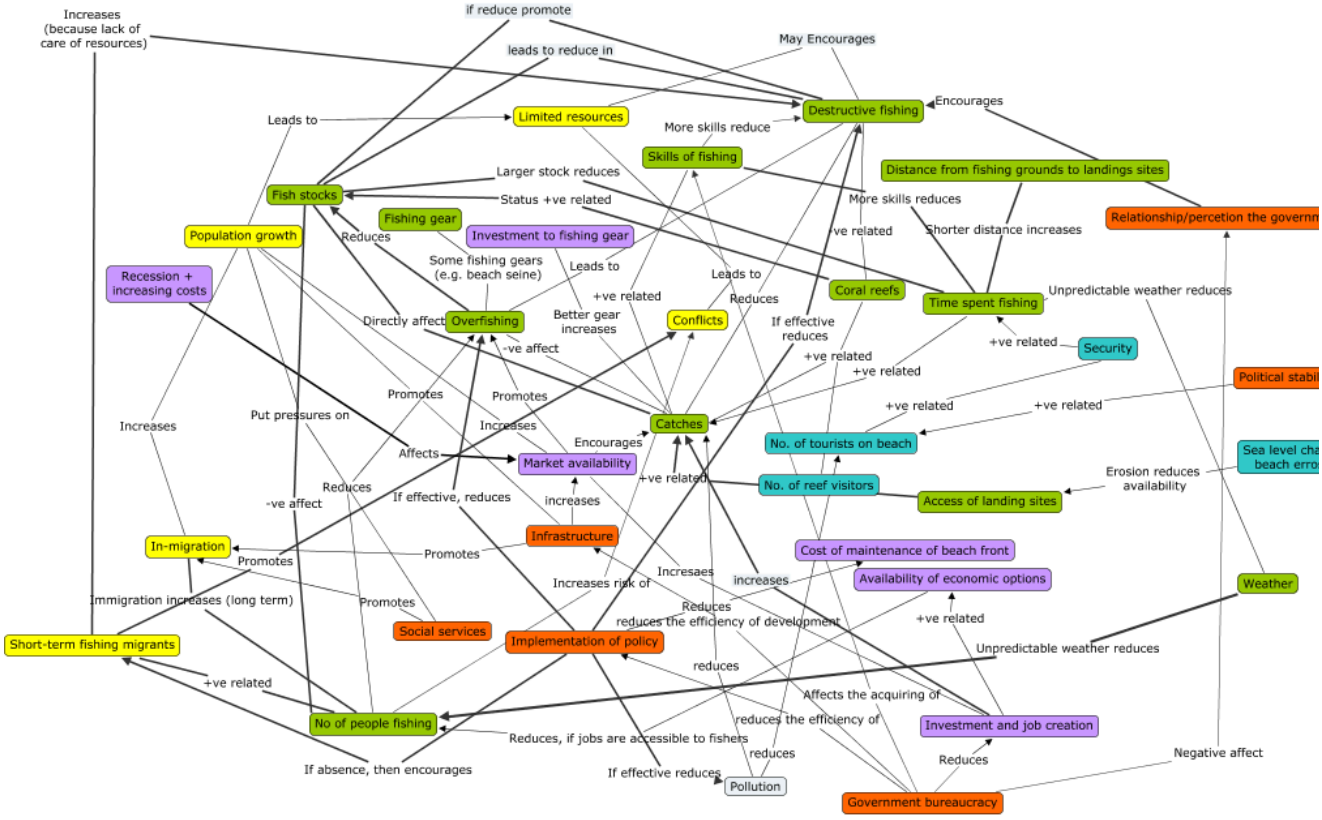

Figure S5. Yellow: Population, Orange: Governance, Purple: Economy, Blue: Tourism, Green: ecology

The model

This analysis provided the general structure of the model. “Social factors” like ‘governance’, ‘economy’, ‘population’ would drive the ecological dynamics which in turn would affect the wellbeing of different groups. With this structure, the ecological model (built in Ecopath) was

put at the center of the toy-model. The ecological model (built on Ecopath) has "fishing effort" as key input parameters. For this reason the "social components" of the toy-model were linked to various levels of fishing effort.
Qualitative in-depth wellbeing research was used to model how the wellbeing of various social groups would be affected by the ecological system. Wellbeing research on this case is published in Abunge et al. (2013). The levels of wellbeing was reduced to "earning capacity" in order to link to the quantitative outcomes of the ecological system. Drawing from the qualitative wellbeing research Table 2 specifies the linkages that were identified between "earning capacity" and ecological outputs from the ecological model.

The model was designed in Excel using fuzzy-logic rules to create the linkages between the variable. Results from ecological simulations were exported from Ecopath and built as reference tables in Excel allowing for the linkages with fuzzy-logic rules.

Table S2. Linkages between ecological outputs and primary stakeholders 'earning capacity'.

Stakeholder Group	**Ecological output**	**How their earning capacity is affected**
Beach Seine Crew	Beach seine catch rate (beach seine CPUE)	Earning capacity is directly linked to how much they fish and how much that ecology yields on a given effort.
Beach Seine Captain	Beach seine catch rate (beach seine CPUE)	Captains own the gear and have more resources, therefore they are not as vulnerable to fluctuations in CPUE
Other fishers	Mixed gear catch rate (other gears CPUE)	Earning capacity directly linked to CPUE of 'other gears' (speargun fishing, net fishing)
Male traders	High quality fish (biomass output of certain species and sizes)	Male traders have access to market in hotels and local restaurants and usually buy larger size fish. The actual biomass of fish available at the beach affects their earning capacity
Female traders	Low quality fish (biomass output of certain species and sizes)	Female traders usually buy small fish or certain species that can be sold in markets.

Model revision process

The overall behaviour of the system was evaluated by experts before the second workshop. During the second workshop, on the first day the goals and intentions of the model were

explained as well as the process that led to the current version. Then, in small groups, participants were guided through each of the linkages that were present in the current version of the model and they were able to suggest modifications either adding or removing links, or defining the strength of each link (Table S3). Based on the suggestions, modifications were done overnight between day 1 and day 2, either in adding/removing fuzzy-logic rules (to add or remove links) or fine tuning the existing rules (to strengthen or dampen the effects of existing rules). It was this collectively revised version that was used during the workshop then to explore the notion of tradeoffs and learn about their implications for policy and management.

Table S3. Model revisions during workshop 2. Adapted from Supplementary material of Daw. et al. 2015

	Input	**Change**	**Output**	**Comment**
1.	Population	Add Negative Link	Ecosystem	Population increases in Mombasa have a direct effect on ecosystem through habitat degradation and pollution.
2.	Tourism	Add Negative Link	Ecosystem	Tourism has direct effect on ecosystem through pollution (e.g. effluents from swimming pools)
3.	Prices	Add Positive Link	Male Trader Wellbeing	Price of fish positively affects male traders because for each fish sold, there is more profit.
4.	Prices	Add Negative Link	Female Trader Wellbeing	Above a certain price for fish, female traders cannot gain access to the market.
5.	Economy	Add Negative Link	Beach Seine Effort	Economic growth increases livelihood alternatives for beach seiners (e.g. construction jobs)
6.	Other Jobs	Add Positive Link	Other Fishers Wellbeing Male Traders Wellbeing Female Traders Wellbeing	Availability of alternative livelihoods particularly benefits other fishers and traders because these groups tend to work in other jobs available to them whilst maintaining fishing as a source of income.
7.	Other Jobs	Change Existing Link (Reduce Weight)	Beach Seiner Crew	The strength of the link between other jobs and beach seiner crew was weakened to show that beach seine crew often have little training, education, or capital to take advantage of new opportunities.

SCENARIOS

In a context of change and uncertainty scenario development is a way to explore possibilities for the future that cannot be predicted by extrapolation of past and current trends.
Based on input from stakeholders during the first workshop in Mombasa, the systems diagrams and discussions, the team created four scenarios of plausible futures for the next 15 years of Mombasa region. These stories were reviewed with local experts and were used as part of the workshop 2 to stimulate discussions on winners and losers under each scenario and potential solutions and mitigation strategies.
Each storyline has a different policy emphasis (drivers), intermediate variables and potential outcome. The purpose in developing these stories was to encourage stakeholders to consider some of the positive and negative implications that the different development trajectories have in the wellbeing of different stakeholders groups. Table S4 summarizes the contrasts between the 4 scenarios.

Table S4. Structuring 'forces' of scenarios

Scenario	Policy Emphasis	Intermediate Variables	Initial Outcomes
A	Conservation	Prices Access	Loss of fish, exclusion of Beach Seiners.
B	Welfare-based, Populist	Productivity	More fishers
C	Development, Tourism	Prices, Catch, Beach Seine Effort	Enforcement of beach-seine ban, less fishing livelihoods
D	Offshore fisheries	Decreased fish prices, decreased effort, coral bleaching.	Decreased number of fishers, decreased wellbeing for inshore fishers.

Story A – 'Aquaculture'

Scenario	Policy Emphasis	Intermediate Variables	Initial Outcomes
A	Conservation, Aquaculture	Prices, Access	Loss of fish, exclusion of Beach Seiners.

The story:

A global recession has impacted the number of international tourists in Mombasa region and the economic growth of Kenya overall. This reduces immigration rates from other parts of Kenya. Local tourist businesses focus on low-volume, eco-tourism rather than mass tourism and there is limited additional of tourism infrastructure. The new government has less emphasis on individual rights and policies are pushed top-down with little engagement with

local communities. Environmental policies are strictly enforced with the influence of remaining ecotourism operators. The ban on beach seines is strictly enforced displacing fisher folk from this livelihood. Inland and coastal aquaculture begins to develop providing low-income livelihoods and cheap fish (in competition with coastal fisheries) which persuades more fishers to diversity their livelihood. As a result of the removal of beach seining and reduction in fishing effort, the condition of corals, seagrass, and near-shore fish stocks improve. Those fishers who do remain enjoy high catch rates of high quality (large) fish, but make limited money due to limited demand and competition from aquaculture that has been implemented around Malindi.

Activity B – Crowded Fishery

Scenario	Policy Emphasis	Intermediate Variables	Initial Outcomes
B	Welfare-based, Populist	Productivity	More fishers

The story:

A government with strong ideas of inclusion and popular policies has enforced individual rights and community participation. Fisheries are managed by county governments and power is devolved to communities and supported by better healthcare and educational programs. There is a reluctance to enforce environmental regulations which displace livelihoods and a skeptical approach to large development proposals with limited benefits to local people. Meanwhile several years of drought combined with ethical and political tensions in other regions of Kenya have driven people to the coast. Mombasa is a safe haven against problems in other parts of Kenya and because of its newly implemented social policies.

However few occupation options are available given the low economic growth. Mombasa's tourist industry struggles and low occupancy rates lead to redundancies in the tourism sector. Lacking of other job options many young men enter fisheries, especially as laborers in the beach seine fishery, which is legalized in response to popular demands for jobs and sources of cheap fish. Immigrants also seek work in fish trading and frying. The demand for cheap fish products from the growing local population is high and marines resources are strongly exploited. Fish traders gather around the arriving boats at the beach to find only small and cheap fish in fisherman's nets.

Activity C - Development

Scenario	Policy Emphasis	Intermediate Variables	Initial Outcomes
C	Development, Tourism	Prices, Catch, Beach Seine Effort	Enforcement of beach-seine ban, less fishing livelihoods

The story:

Kenya is enjoying a prosperous phase. A pro-business government and low taxation attracts foreign investments. Mombasa is a reflection of the booming economy with its newly expanded port and influxes of local and international investments that fund infrastructure, hotel investments that promote a growing mass beach tourism market. Port development raises land prices and standard of living. Some fisher folk are attracted out of fisheries into

opportunities in construction, tourism, and services or as a result of displacement from their landing sites by other economic interests. Those fishers who persist benefit from lowered competition at sea, high demand, and high fish prices. Their catch rates are good and include larger species. Some immigrants find work on beach seine crews that still operate illegally in certain areas. In time, the unconstrained beach development results in beach erosion, which has an impact on tourism and fish landing sites. Conflict between beach seiners and other types of fishers rise. Political tensions are also stoked by increasing levels of inequality as some entrepreneurs get rich and establish exclusive residences along the coast.

Activity D – Offshore Fisheries

Scenario	Policy Emphasis	Intermediate Variables	Initial Outcomes
D	Offshore fisheries	Prices, Effort, Coral bleaching.	Decreased number and wellbeing of inshore fishers.

The story:

Implementation of a project on external donor funding – e.g. Kenya Coastal Development Project – leads to provision of vessels, training, and fisheries marketing infrastructure along the coast by Mombasa. This supports development of an offshore fishery targeting semi-pelagic deep water fish with modern ring nets and aided by fish finding technology. Initial trials are variable but generally successful and within 5 years 10 large vessels operate from the coast immediately north of Mombasa. These are collaboratively owned by members of fisher organizations and BMUs and crewed by locals as well as migrant Tanzanians as hired laborers and captains. The catches from these vessels are significantly larger than those from small-scale nearshore gears and beach seines, leading to a reduction in the price per kilo of fish landed from the reef and seagrass fishery. The number of fishers using spear, small nets, handline and beach seine reduces due to some fishers receiving training and joining the new

larger vessels, and some opting to leave fisheries in the light of market competition with the new fishery. This leads to a slow recovery of fish in the nearshore habitats, but coral bleaching over repeated years reduces diversity and cover of corals. High catches from the offshore fishery attract investment from local business interests, but fluctuations in catches make it difficult to repay loans on investment several local and community owners have to sell their vessels and operations after poor seasons, or due to lack of financial capital and management. Thus within 10 years the offshore fishery becomes consolidated to be owned by a few larger business people who hire crew from outside the area. Some fishers lose access to this fishery as a result and reluctantly return t0 inshore fishing.

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