Local economic and environmental impacts of marine reserves in rural coastal economics

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Environmental and Economic Impacts of (Forest) Reserves

Can protected areas alleviate poverty in surrounding communities?

- **Yes:** Ferraro et al. 2011; Ferraro and Hanauer 2014
- **No:** Sims and Alix-Garcia 2017
- **Sometimes:** Ferraro et al. 2013

Conservation and economic success of a reserve is a function of

Strictness of reserve regulation,

Existence of tourism,

Other forms of economic heterogeneity between communities

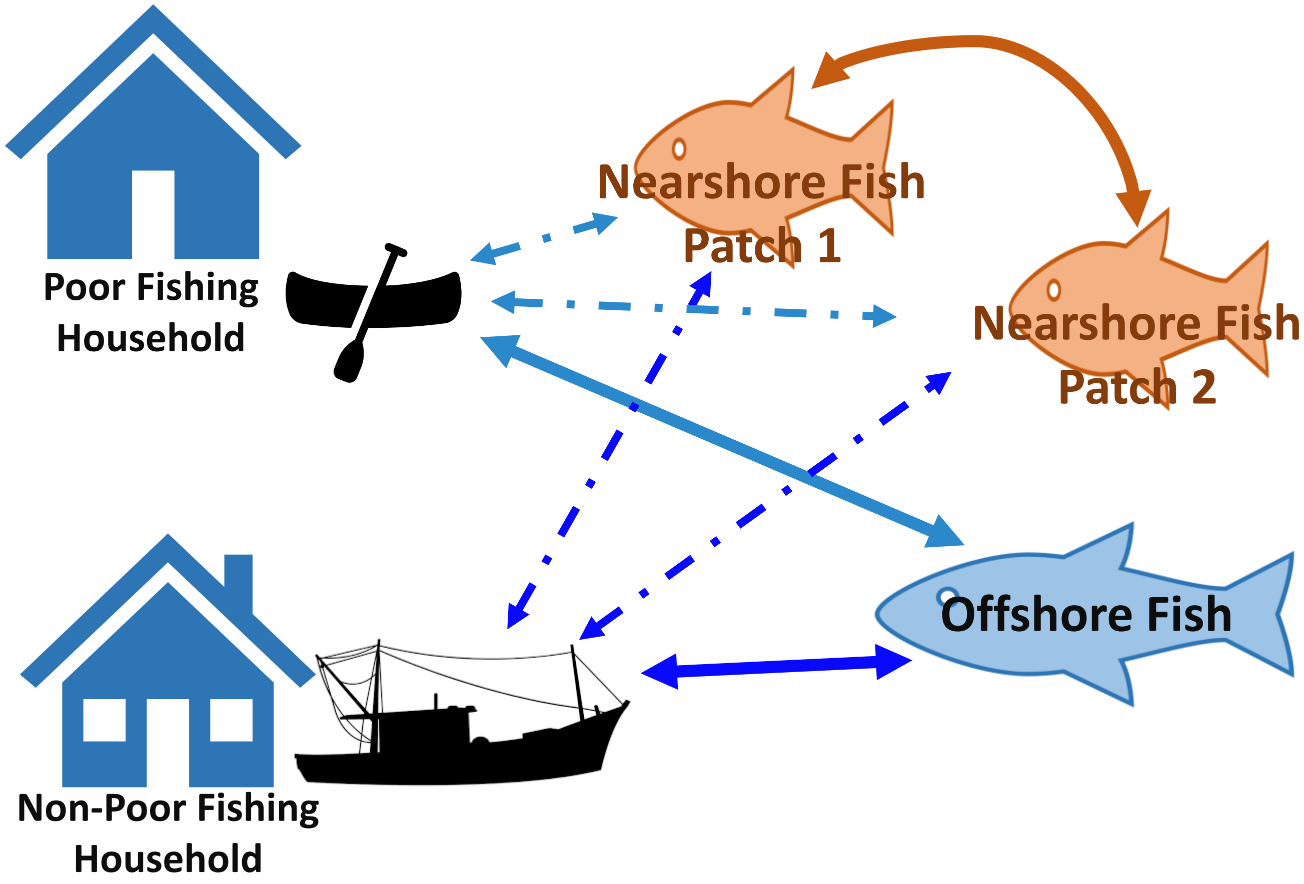
Heterogeneity over space affects performance of a marine reserve

Ecological characteristics

(Polacheck 1990, Holland & Brazee 1996, Brown et al. 2015)

Economic characteristics

(Sanchirico & Wilen 1999, 2001, 2002, Smith & Wilen 2003, Raassweiler et al. 2012, Reimer & Haynie 2018)

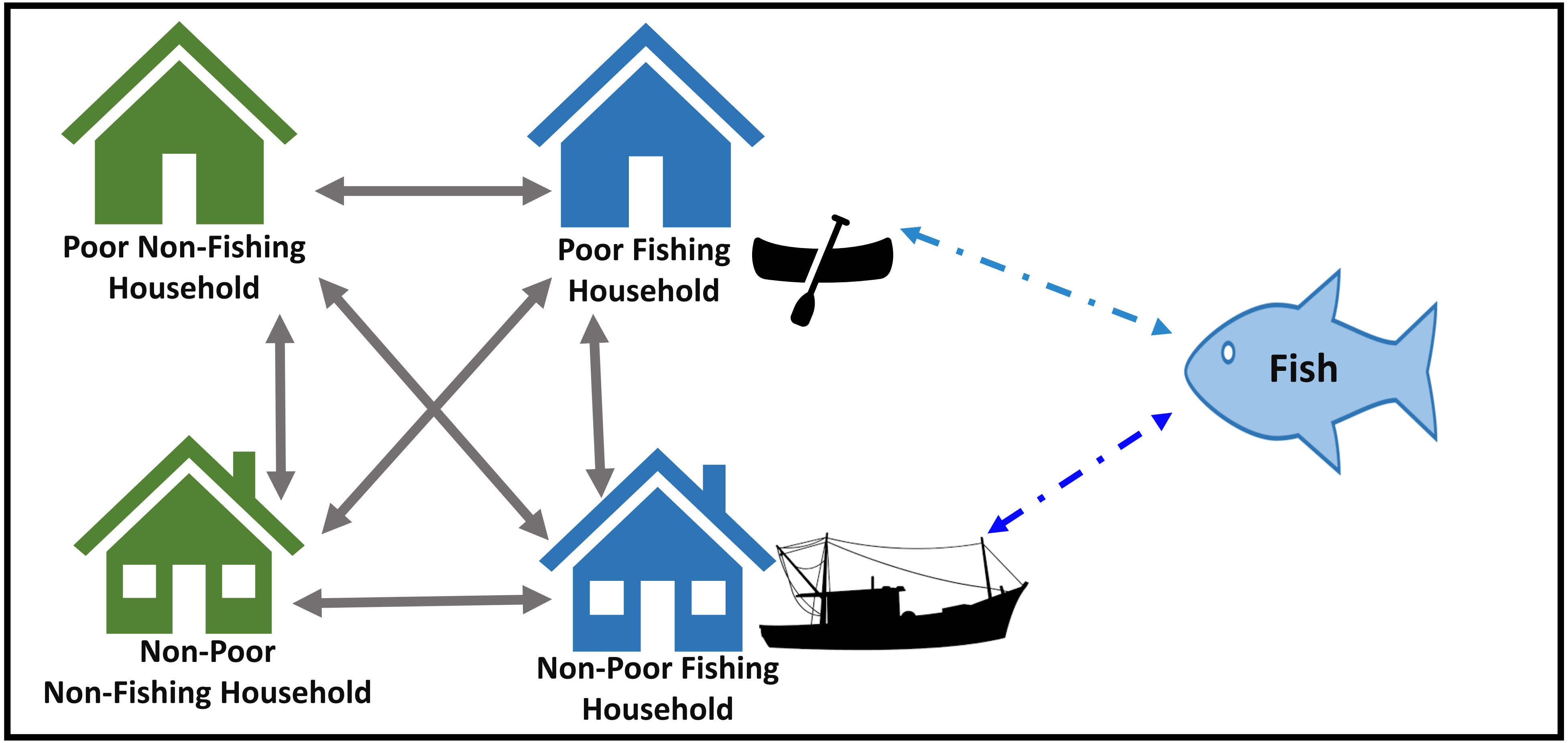


Local input & output market failures impact household production decisions

(Taylor & Filipski 2014)

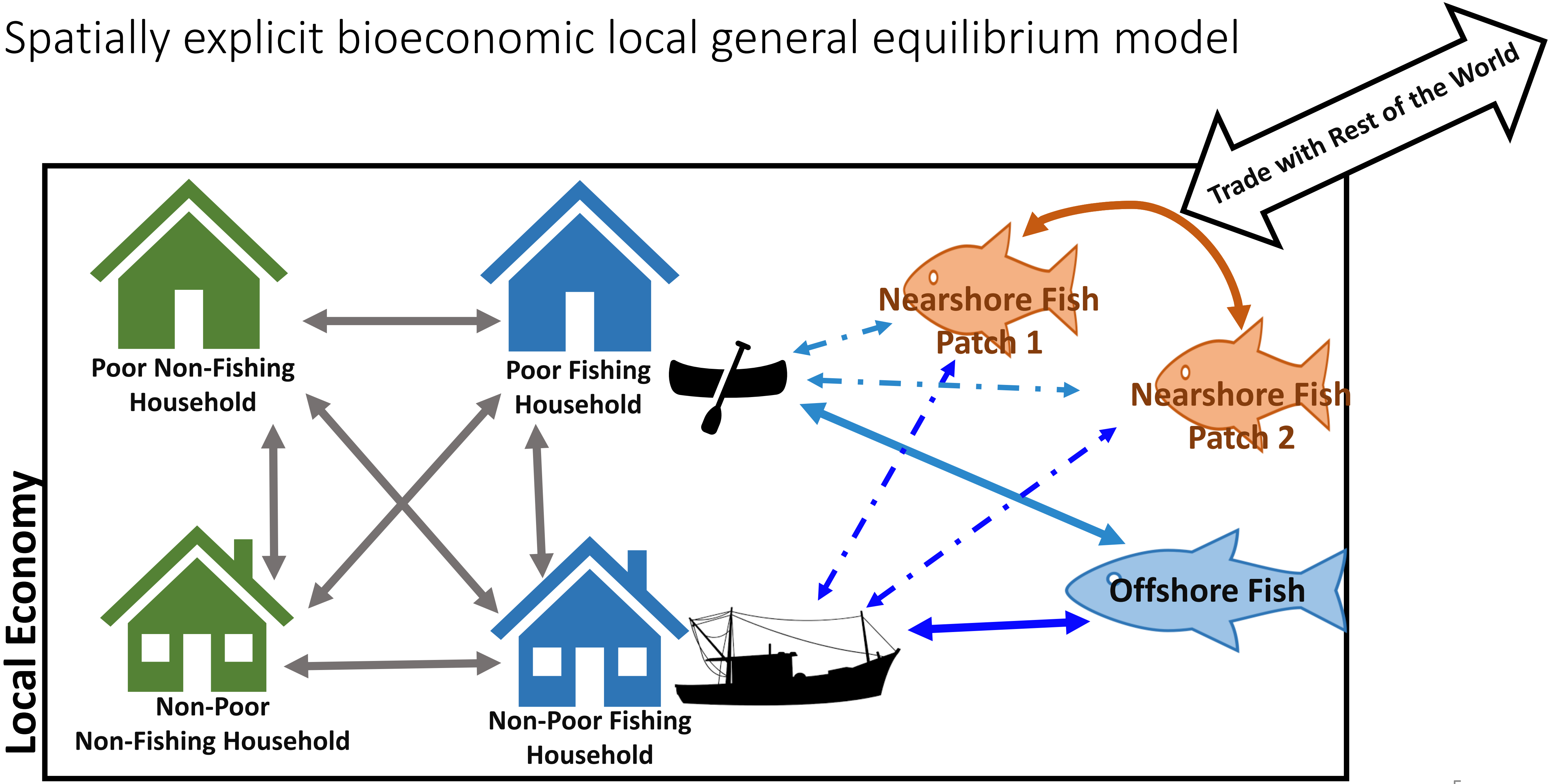
Fishing decisions are linked to other economic activities

(Liese et al. 2007, Wilen 2013, Manning et al. 2014, Gilliland et al. 2018)



Research method:

Spatially explicit bioeconomic local general equilibrium model



Research Questions:

How is the nearshore fish stock impacted by a marine reserve?

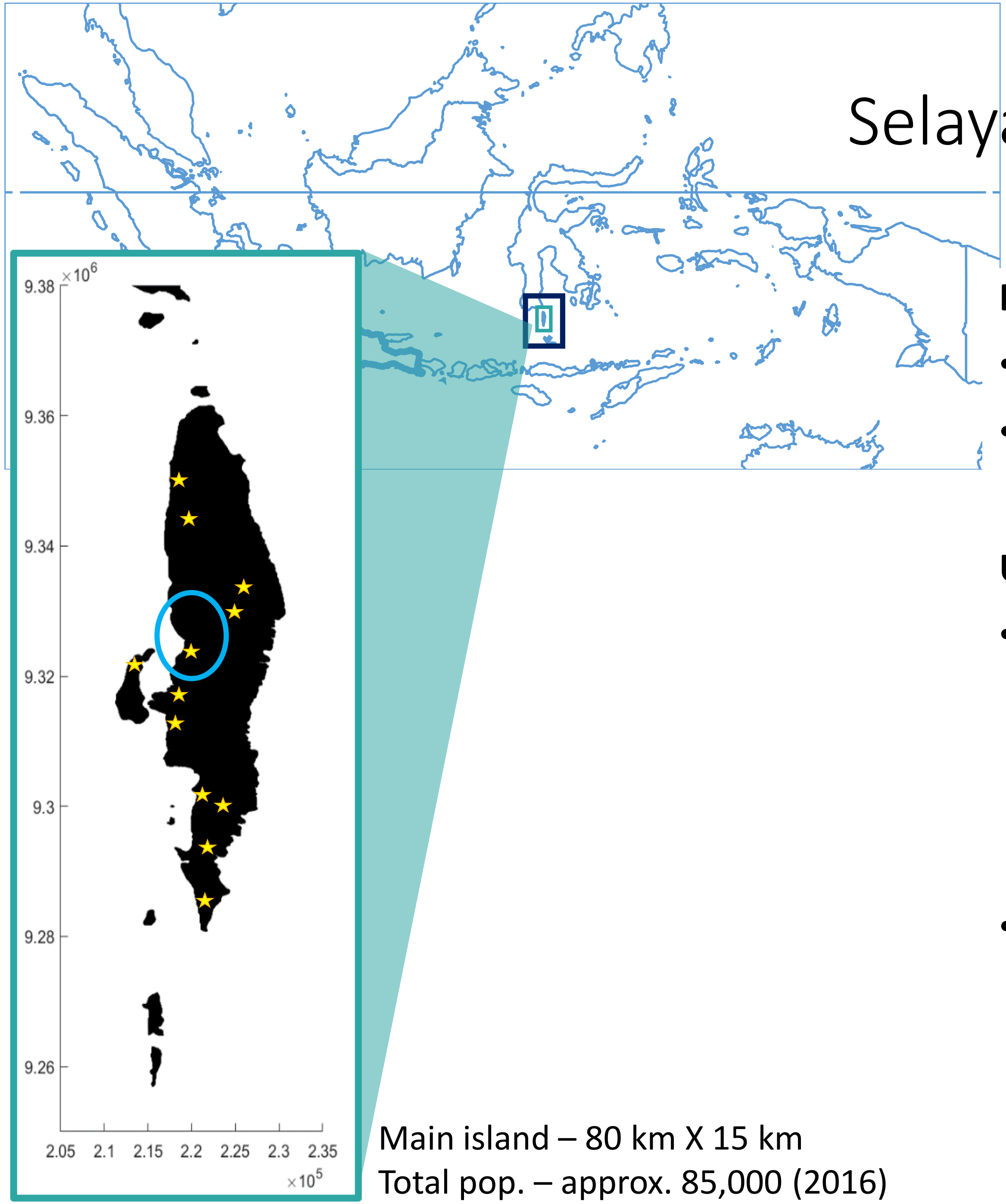
How does the marine reserve impact incomes?

of fishing households (differences over space)?

of poor households (both fishing and non-fishing)?

How do results change under different market structure assumptions?

Selayar Island, South Sulawesi, Indonesia



Main island – 80 km X 15 km
Total pop. – approx. 85,000 (2016)

Data Collection: October 2016

- 487 households randomly selected from 12 villages (★)
- 257 businesses randomly selected from urban area (◯)

Use economic survey data to

- Parameterize the local economic model
  - Household production (Cobb-Douglas CRS)
  - Household consumption
  - Government provided goods and services

- Calibrate the local economic model:
  - Local production satifies demand for local goods

Modeling Framework Component 1 – Local general equilibrium model

Main Industries:

- Agriculture & livestock: 52% of households
- Marine fisheries: 18% of households
- Small household enterprise – restaurants, retail, services

Offshore & nearshore fishing are separate production activities

- Both use labor, and fishing capital
- Each has their own, independent fish stock

Representative households:

- Northern Poor Fishing
- Northern Non-Poor Fishing
- Central Poor Fishing
- Central Non-Poor Fishing
- Southern Poor Fishing
- Southern Non-Poor Fishing

- Poor Non-Fishing
- Non-Poor Non-Fishing

Modeling Framework Component 1 – Local general equilibrium model

Output market imperfections (selected)

- Nearshore fish traded in local markets → endogenous price
- Offshore fish traded in local & regional markets → exogenous price

- Households consume a composite fish good (CES aggregate allows for substitution)

Input market Imperfections

- Fixed local labor supply →economy-level wage
- Thin land & capital markets → household-level shadow prices

Modeling Framework Component 2: Bioeconomic Model

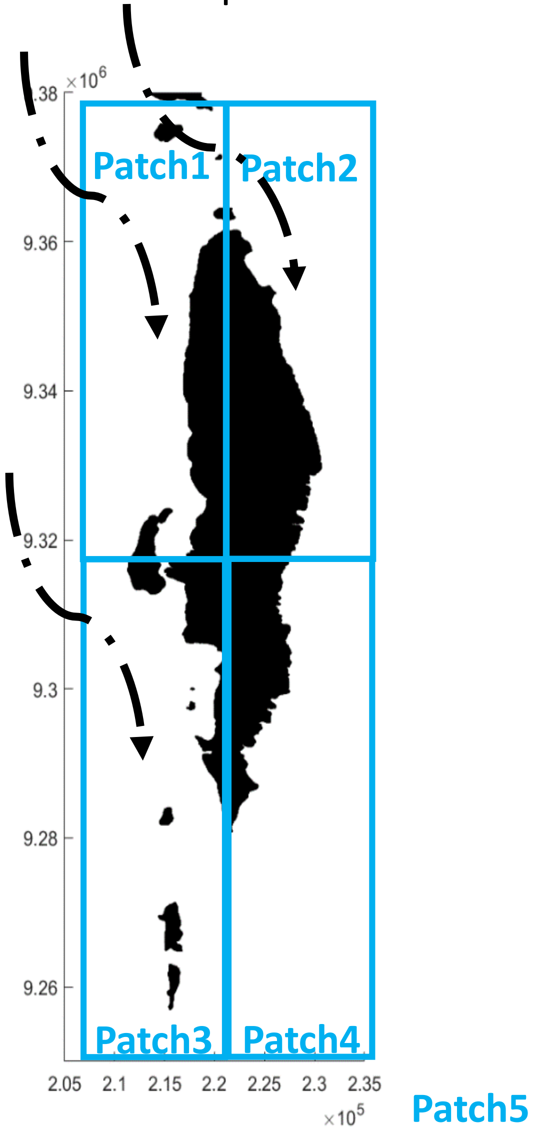
- Both fish stocks are open access resources
    - Rents dissipated within each period

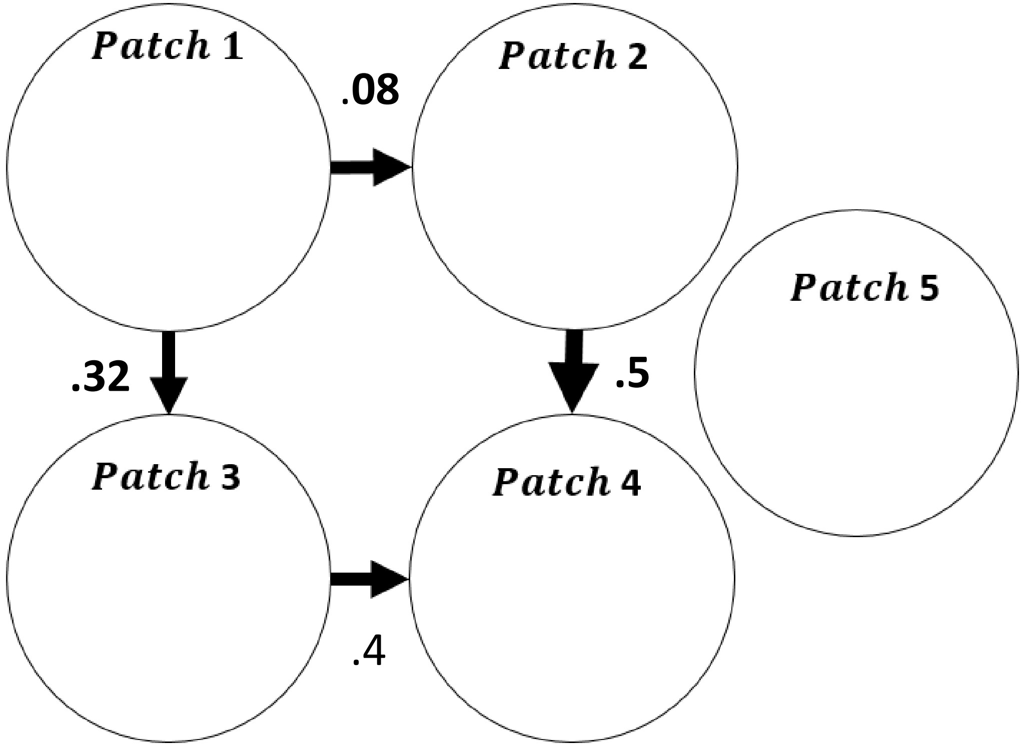
    - Between periods, nearshore fish stocks respond to changes in fishing pressure
    - Offshore fish stock is fixed

- Nearshore fish stocks are in steady state at baseline
  (harvest equals growth less natural mortality)

Modeling Framework Component 2: Bioeconomic Model

Dispersal between patches



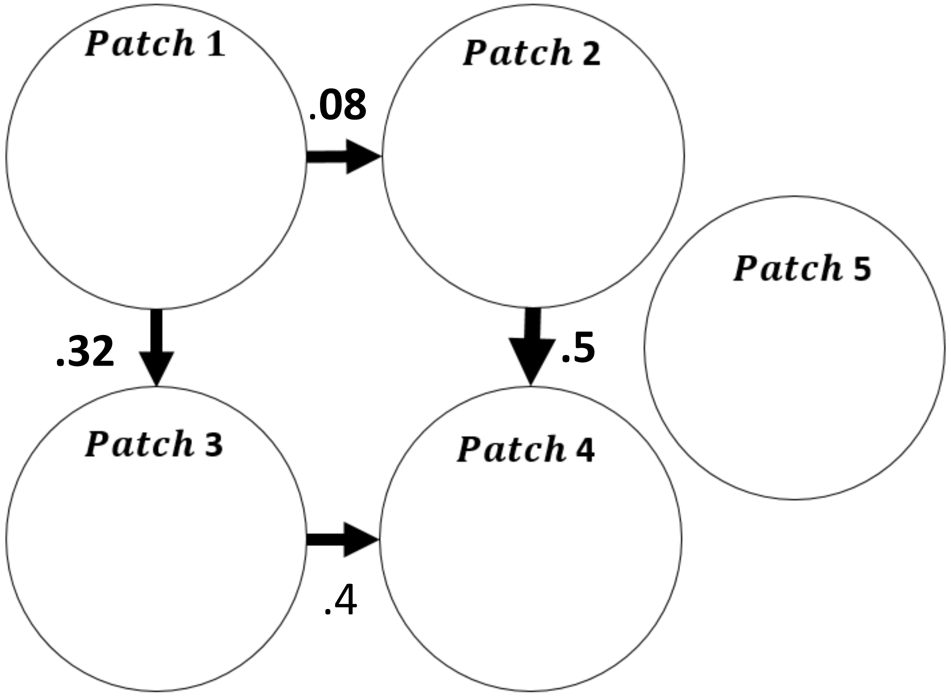


Patch 1: Source
Patch 4: Sink
Patch 5: Independent

Modeling Framework Component 2: Bioeconomic Model
Contribution to local harvest and biomass

Harvest Levels, Baseline Stock, and Potential Stock

	% of harvest (at baseline)	Baseline stock (% of Total)	Carrying Capacity (% of Total)
Patch 1	18	22	23
Patch 2	0.1	2	4
Patch 3	38	46	48
Patch 4	9	3	6
Patch 5	34	27	19



Policy Simulations:
Estimate effect of a reserve

A reserve closes off a portion of the patch, **does not close an entire patch**

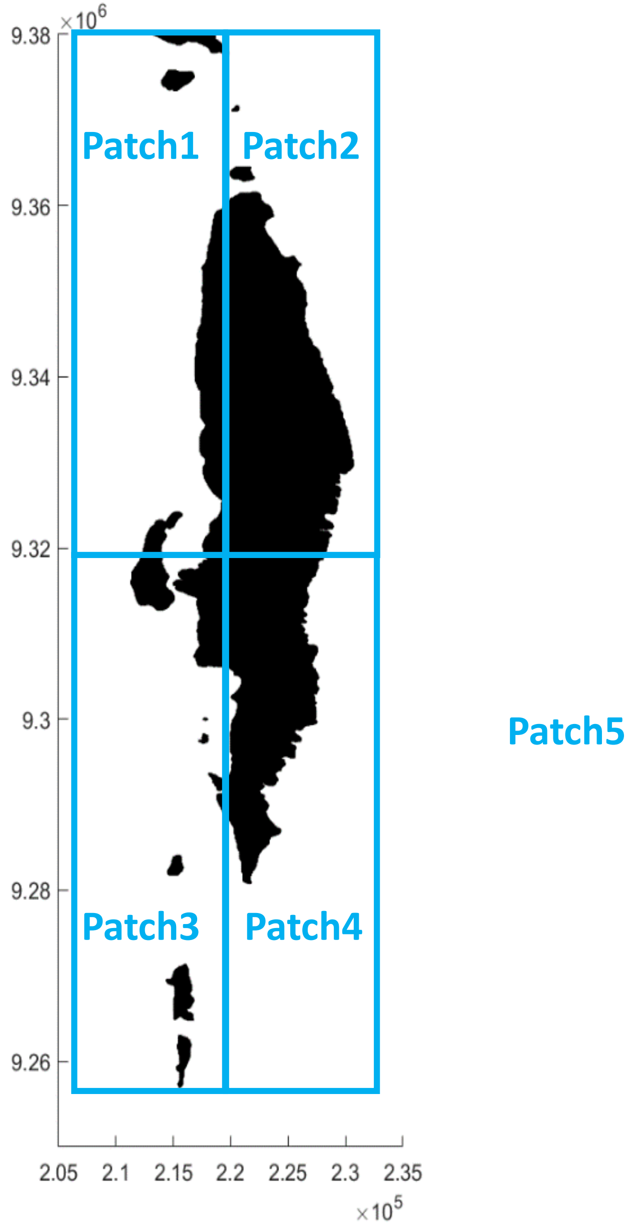
→Increases fishing costs within a patch, holding stock fixed

A reserve increases fishing costs in the patch by 50%

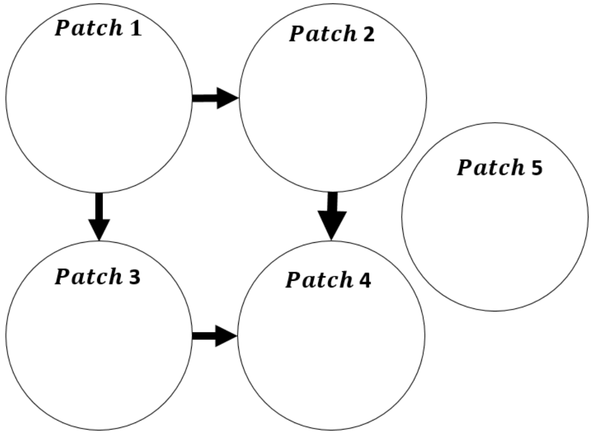
- Cost of fishing in other patches does not change (initially)

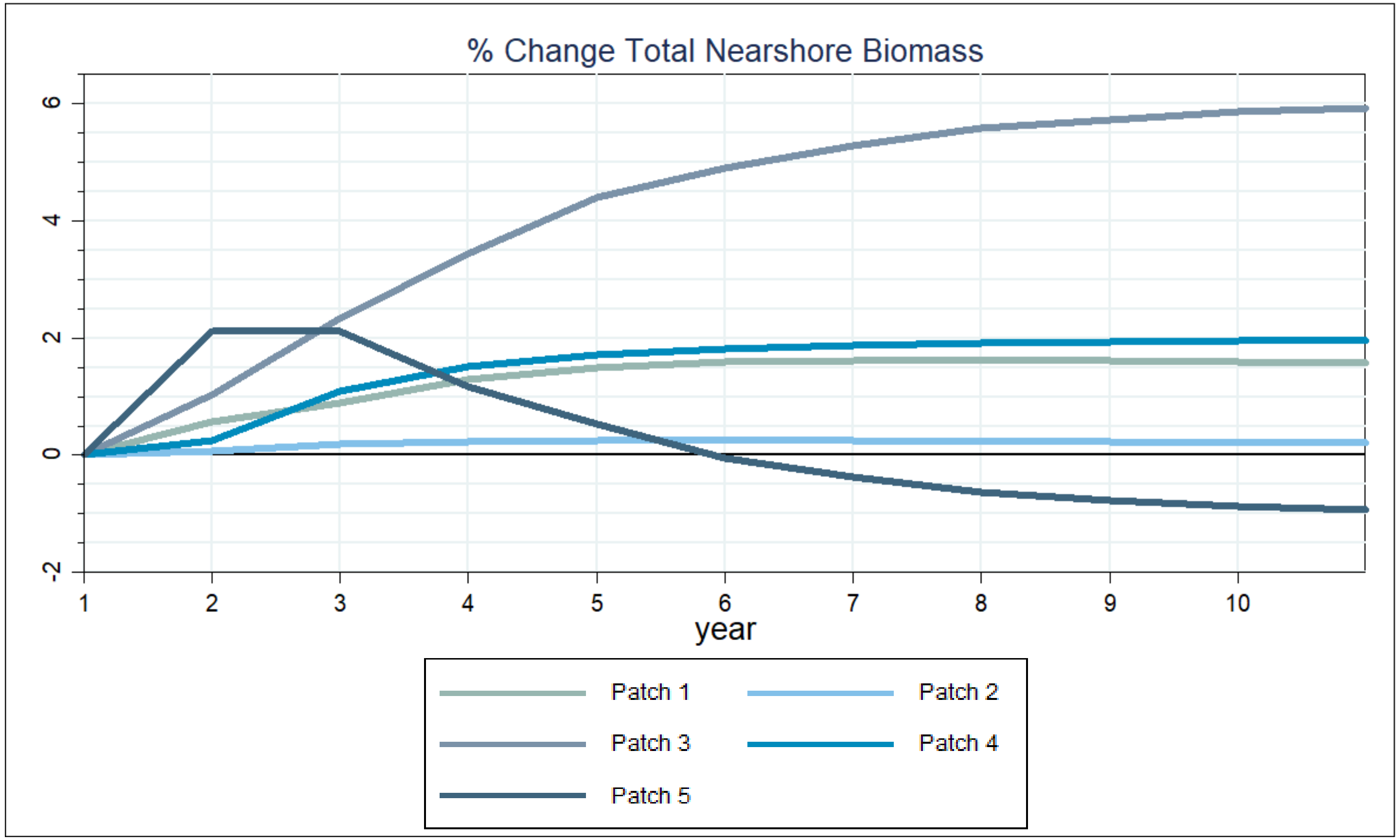
Over time…

- As fish stock within patch rebounds, costs decline
- As fish stock within patch declines, costs increase



% Change in Overall Nearshore Fish Biomass
Comparing performance of different reserves





Only unsuccessful reserve (decrease stock):

Patch 5

- Independent
- Medium contributor to potential biomass

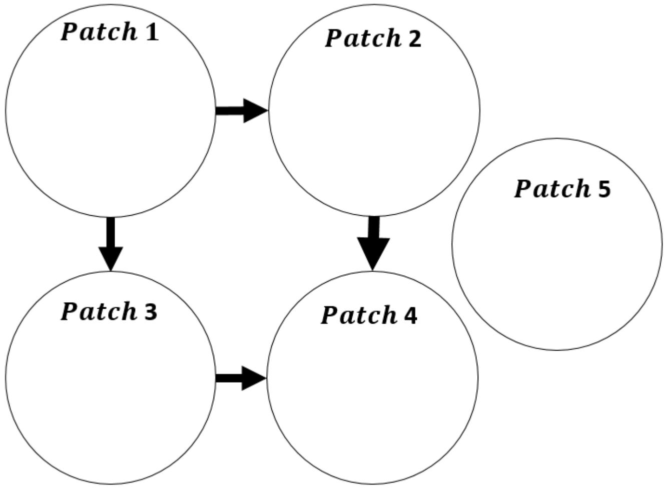
	Baseline stock (% of Total)	% of Total Carrying Capacity
Patch 1	22	23
Patch 2	2	4
Patch 3	46	48
Patch 4	3	6
Patch 5	27	19

% Change in Nearshore Fish Biomass

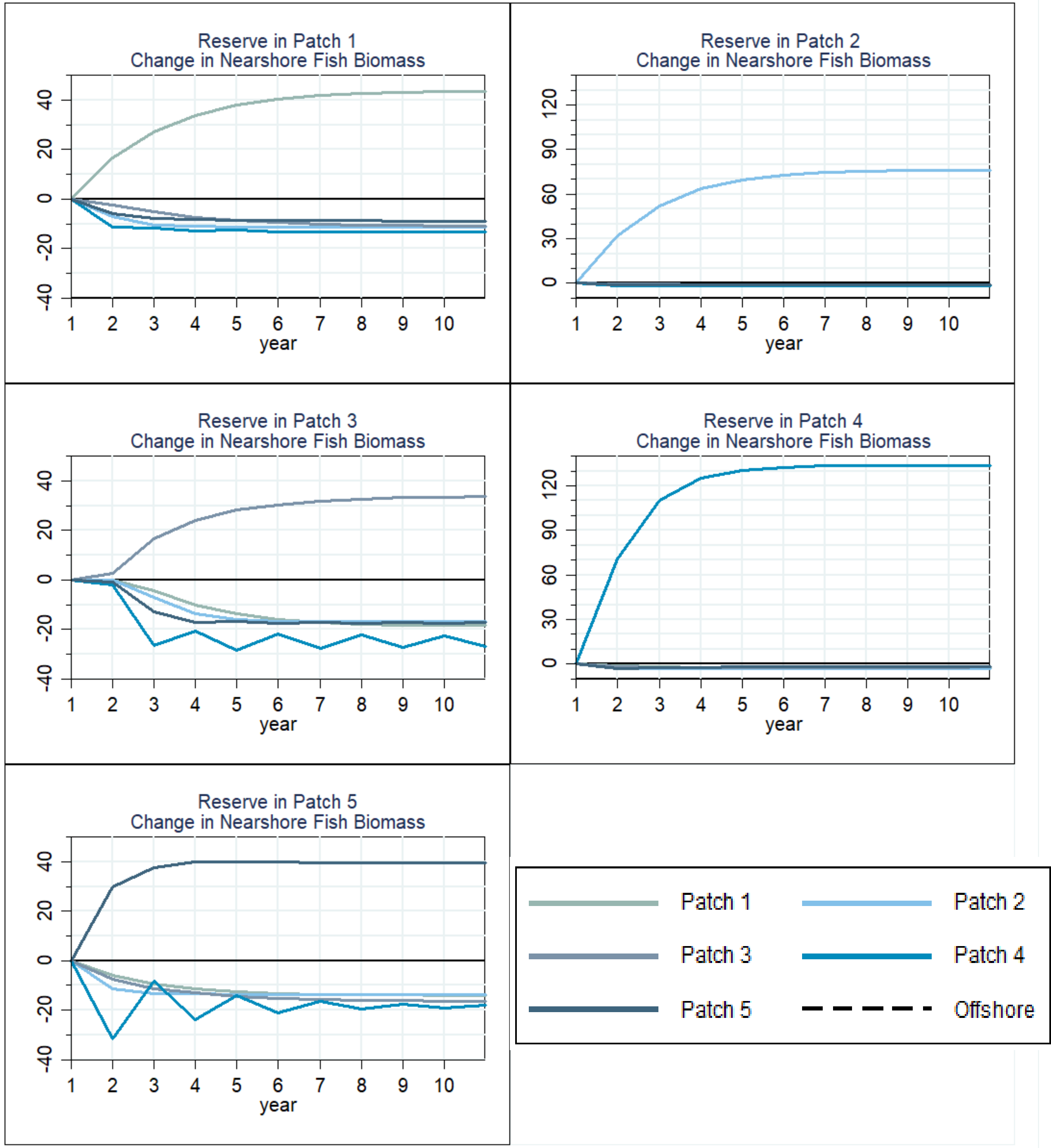
Within each fishing area

In all reserve scenarios:

- Stock in the patch with reserve recovers
- Stock in other patches declines
- Fishing activities shift to other areas



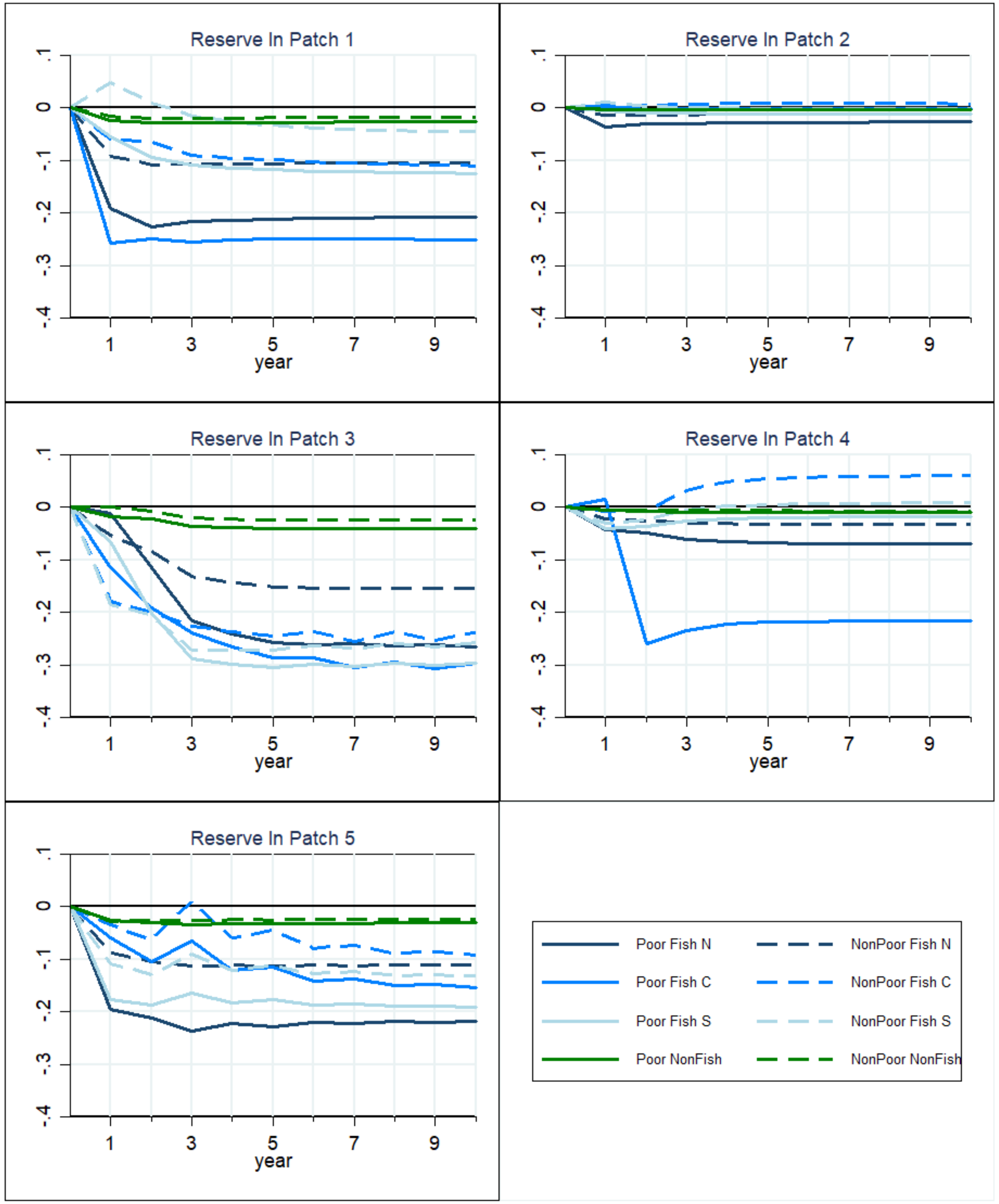
	% of Total Carrying Capacity
Patch 1	23
Patch 2	4
Patch 3	48
Patch 4	6
Patch 5	19



% Change in Real Income
For each representative household

In all reserve scenarios: most real incomes decline

- Fishing households tend to experience larger declines than non-fishing households
- Poor households tend to experience larger declines than non-poor households
- Changes to real income are small



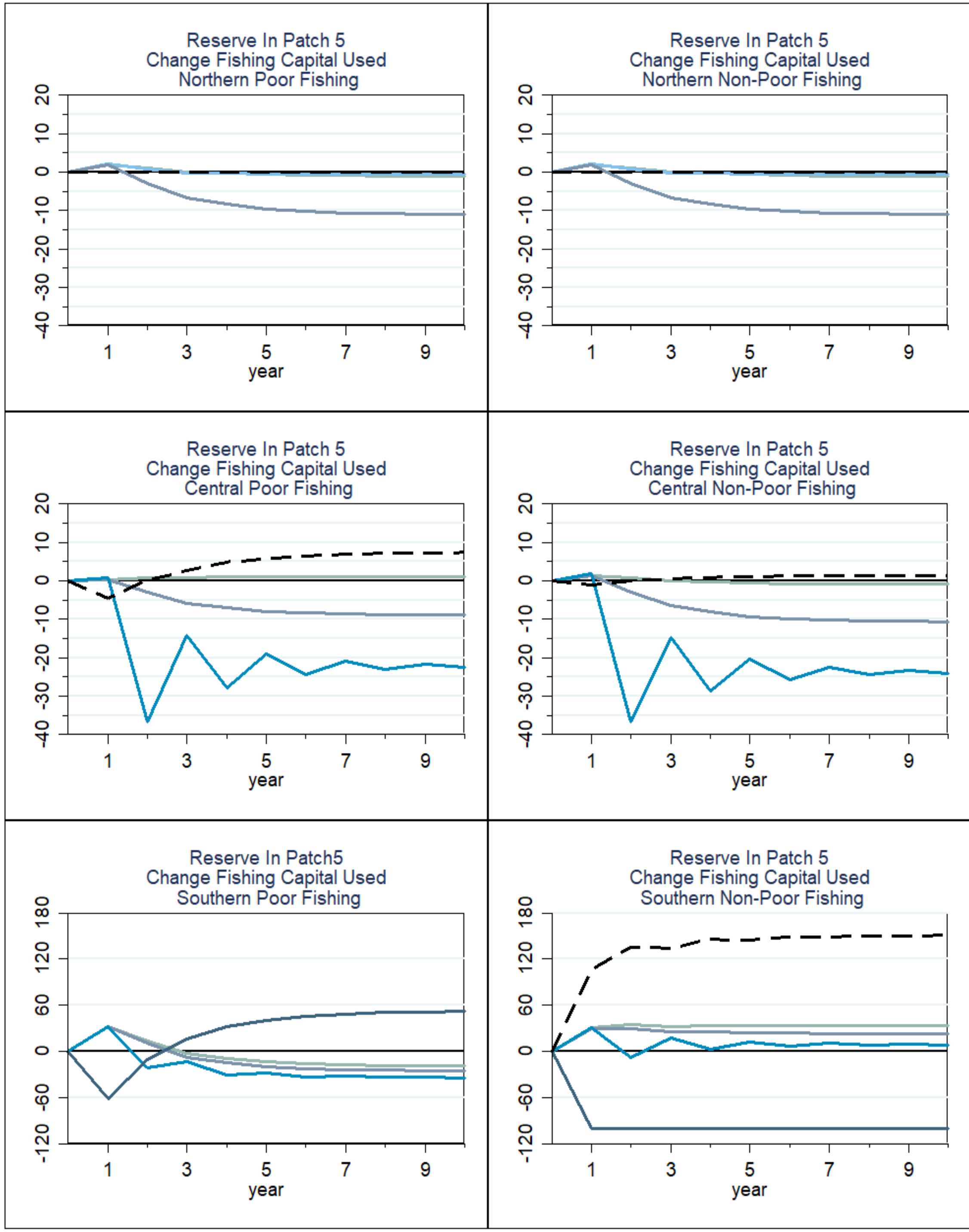
Reserve in Patch 5

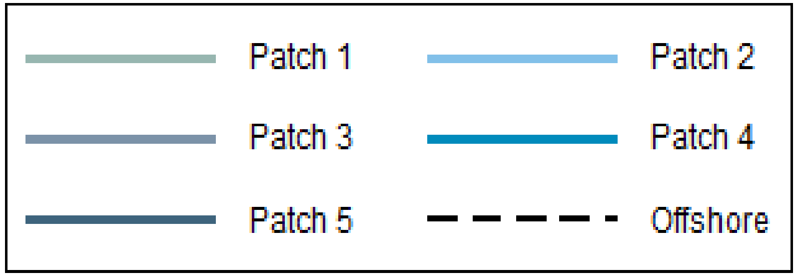
% Change in capital allocated to patches

- Remember: This patch is not ecologically connected to the other patches

- The southern fishing households are directly impacted, and move capital out of patch 5

- Northern and central households respond to higher nearshore fish price, and adjust capital allocation





Reserve in Patch 5

% Change in returns to factor inputs

- All economic sectors are connected through output markets and the local labor market
- Linkages create counteracting mechanisms
- Net impact to household depends on endowments

For example:

Higher fishing costs

→ Lower local harvest

→Higher fish price

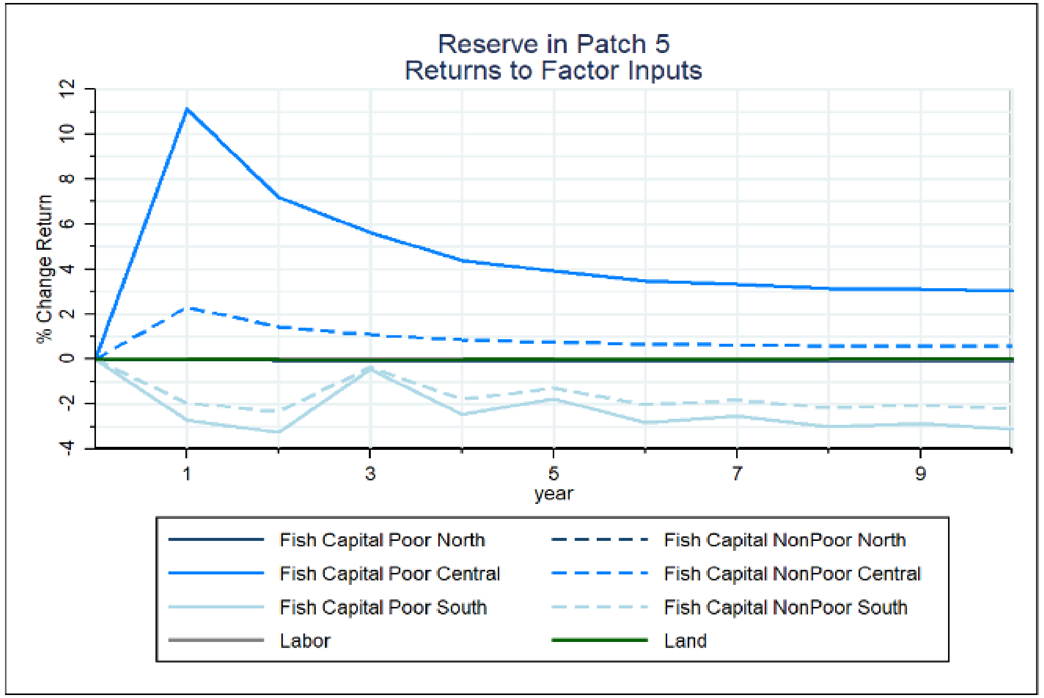
→Increase demand for labor in fisher

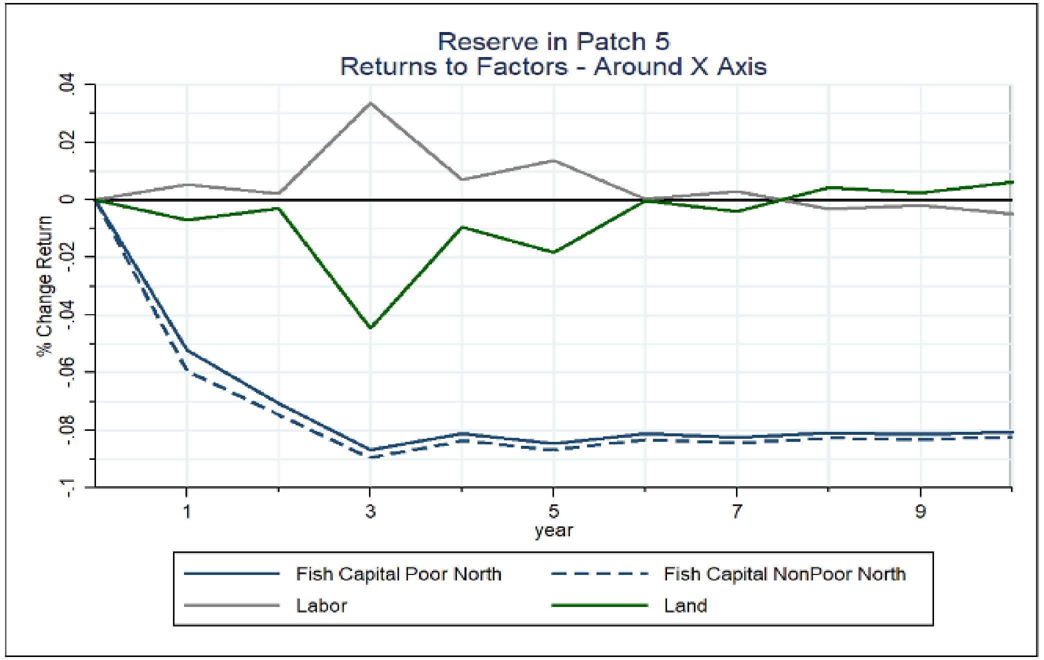
→Lower labor allocated to agriculture

→Agricultural land becomes less productive

While households may benefit from wage increase,

they are hurt by decreased value of agricultural land





Sensitivity of Results
Increasing elasticity of substitution

In preferred model: inelastic substitution between nearshore and offshore fish

price of nearshore fish is elastic with respect to local supply

→ marine reserve leads to an increase in nearshore fish price

Re-run simulations increasing the elasticity of substitution (approaches perfectly elastic)

price of nearshore fish more inelastic with respect to local supply

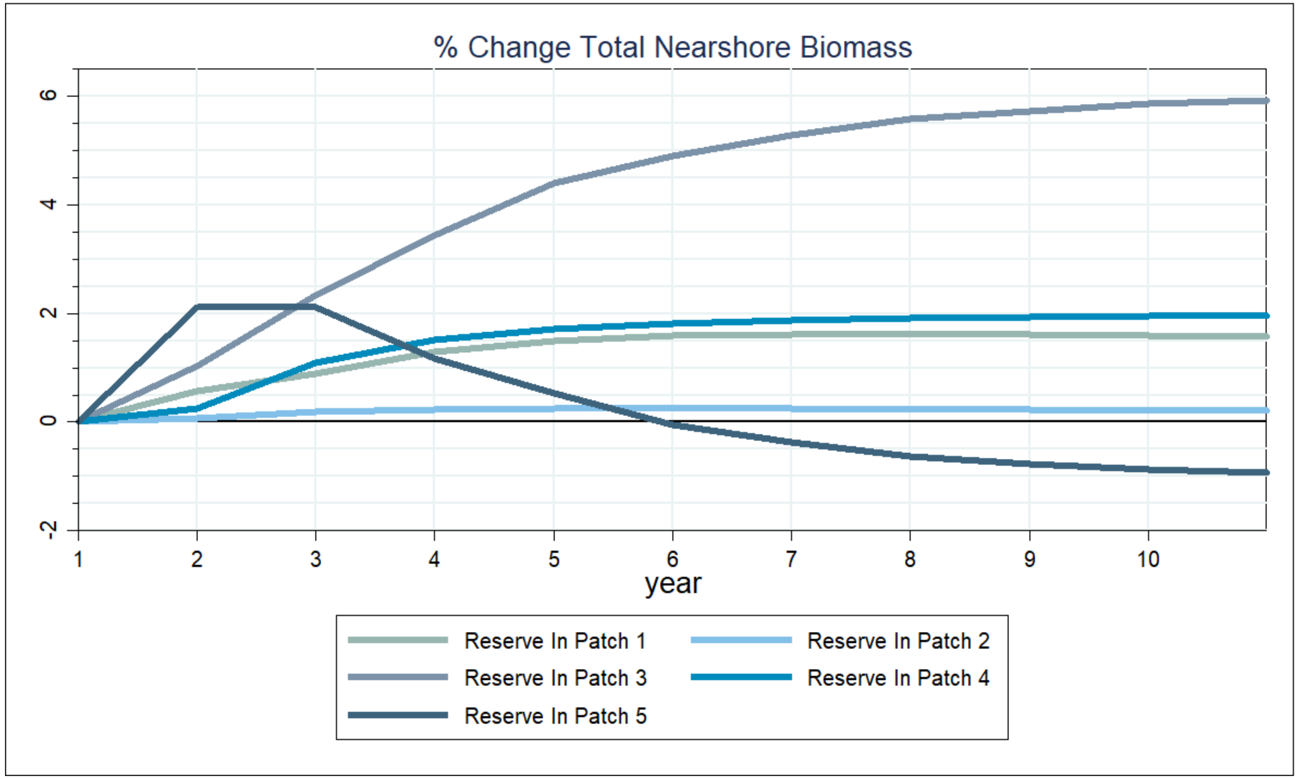
Alternative specification approximates an exogenous nearshore fish price

or an open nearshore fish output market

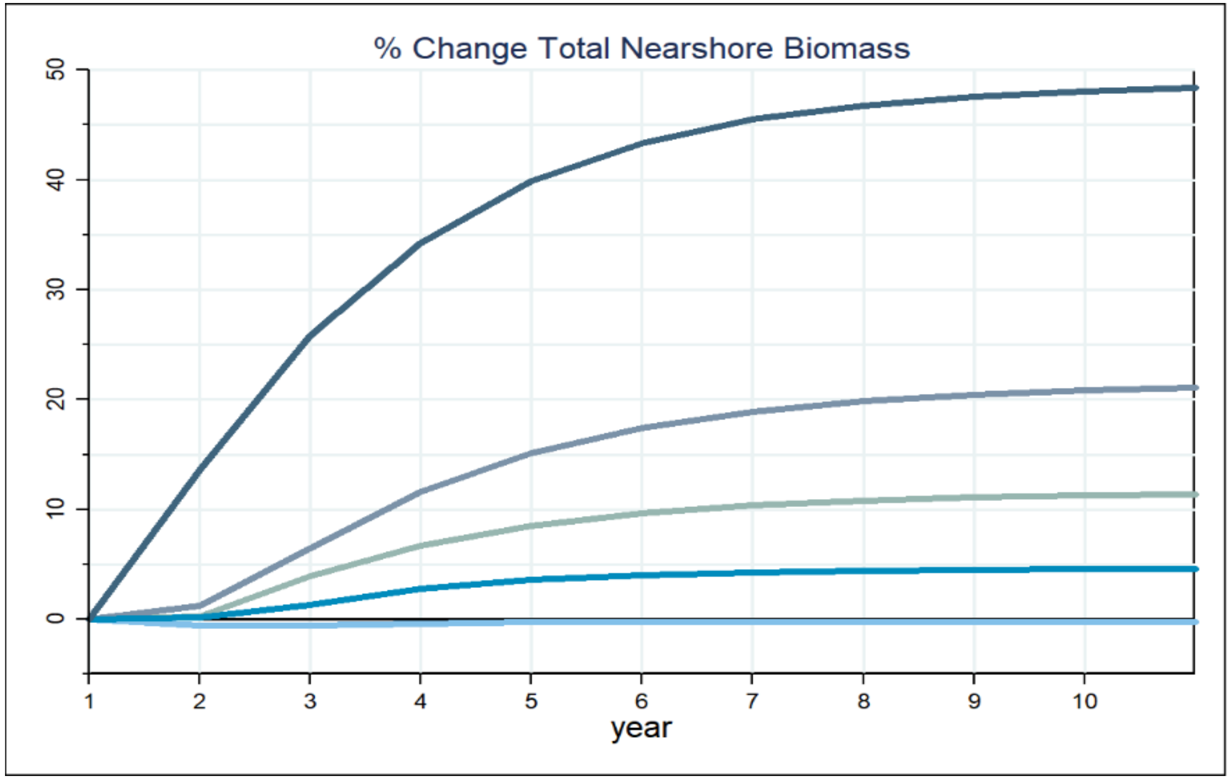
Sensitivity of Results

Almost all reserves achieve greater conservation results

Inelastic substitution

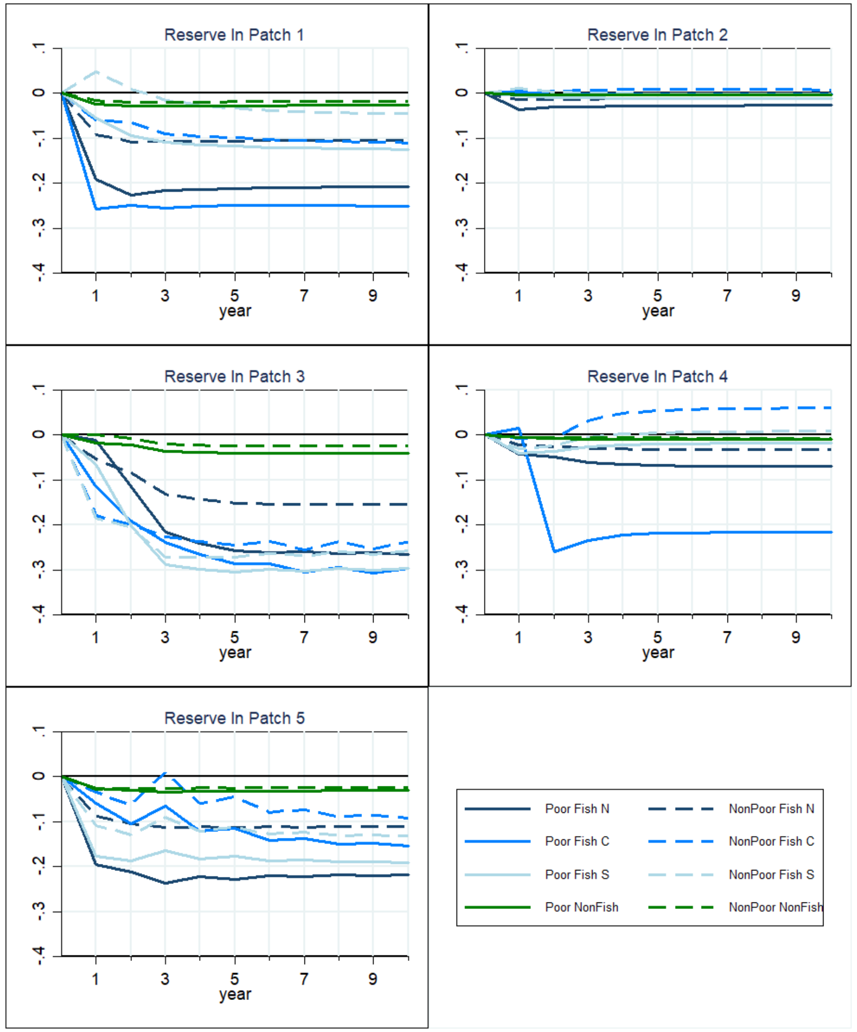


Elastic substitution

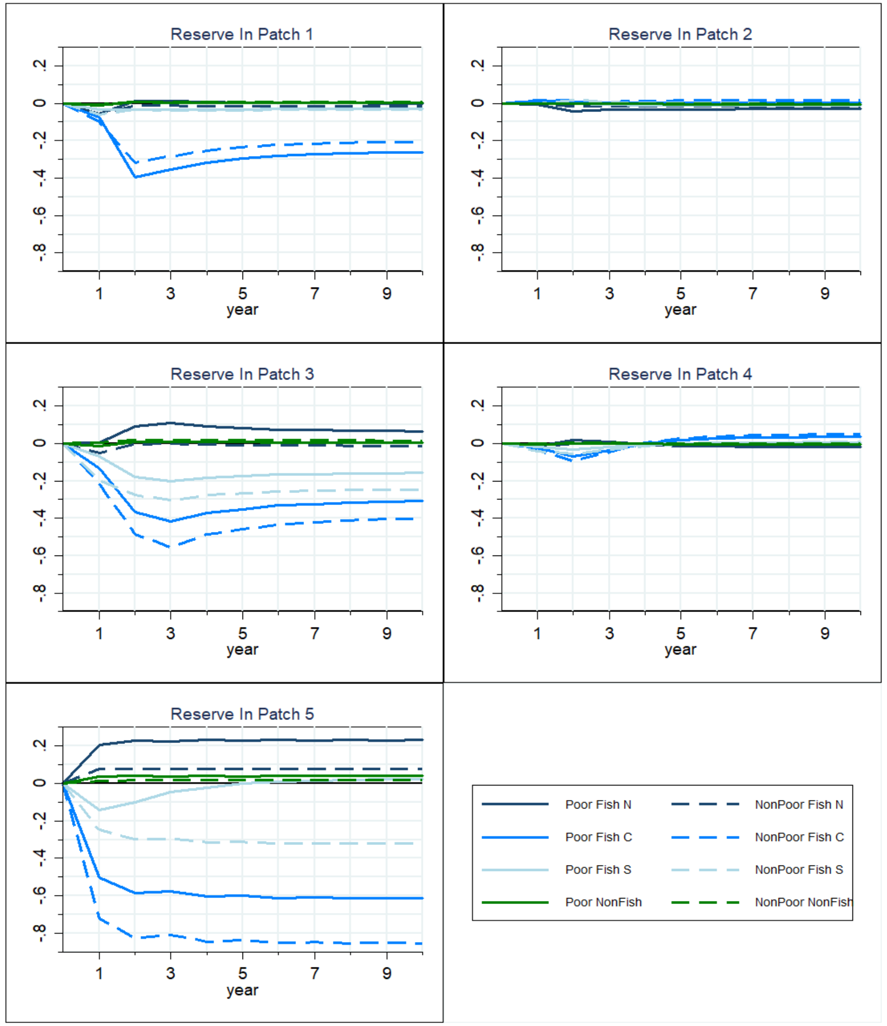


Sensitivity of Results

Inelastic substitution



Elastic substitution



Preferred site location

PV changes to real incomes (USD) & % change in nearshore fish biomass

Inelastic substitution: responsive nearshore fish price

	Reserve				
	Patch 1	Patch 2	Patch 3	Patch 4	Patch 5
All Households	-144	-15	-244	-38	-193
All Poor Households	-35	-4	-48	-14	-39
All Fishing Households	-61	-3	-156	-10	-85
Nearshore Fish Biomass (year 10)	1.6%	0.2%	5.9%	2%	-0.9%

Elastic substitution: non-responsive nearshore fish price

	Reserve				
	Patch 1	Patch 2	Patch 3	Patch 4	Patch 5
All Households	-33	-13	-88	-7	-99
All Poor Households	-7	-4	-11	-2	17
All Fishing Households	-54	-2	-143	-6	-185
Nearshore Fish Biomass (year 10)	11.3%	-0.3%	20.9%	4.6%	48.1%

Conclusions:

- Local market features limit economic and environmental benefits of a reserve
    - Linkages between economic sectors lead to counteracting mechanisms, dampening effects
- Ignoring local market structure lead us to incorrect policy design
    - Changing the responsiveness of nearshore fish price alters the preferred site selection

Full Model Statement – Part 1

Name	Equation
EQ_PVA(g,h)	$PVA_{g,h} = P_g - \sum_{gg \notin gcom} idsh_{g,gg,h} * \left(\left(P_{gg}\right)_{gg \notin gm} + \left(P_{comp_{gg}}\right)_{gg \in gm} \right)$
EQ_QP(g,h)	$QP_{g,h} * vash_{g,h} = A_{g,h} \prod_f FD_{g,f,h}^{\beta_{g,f,h}} * \left[B_{g,t}^{\beta_{g,stock,h}} \right]_{g \in gstk}$
EQ_FD(g,f,h)	$FD_{g,f,h} = \dfrac{QP_{g,h} * PVA_{g,h} * \left[\beta_{f,g,h} + \left[\theta_{g,f,h} * \beta_{stock} \right]_{g \in gstk} \right]}{\left(Wfth_{f,h}\right)_{f \in fth} + \left(Wftv_f\right)_{f \in ftv} + \left(R_{g,f,h}\right)_{f \in fx}}$
EQ_ID(g,gg,h)	$ID_{g,gg,h} = QP_{g,h} * idsh_{g,gg,h}$
EQ_QC(g,h)	$QC_{g,h} \left(\left(P_g\right)_{g \notin gcom} + \left(P_{comp_g}\right)_{g \in gcom} \right) = Y_h * \alpha_{g,h}$
EQ_Y(h)	$Y_h = \sum_{g,f \in fx} R_{g,f,h} FD_{g,f,h} + \sum_{f \in fth} Wfth_{f,h} HFSUP_{f,h} + \sum_{f \in ftv} Wftv_f HFSUP_{f,h} + exinc_h - netsav_h + netremit_h$

Full Model Statement – Part 2

Name	Equation
EQ_HMS(g,h)	$HMS_{g,h} = [QP_{g,h}]_{g \notin gcom} - QC_{g,h} - \sum_{gg} ID_{gg,g,h} + govexp_g$
EQ_VMS(g)	$VMS_g = QP_{comp\ g \in gcom} + \sum_h HMS_{g,h} - TQDForComp_{g \in gin}$
EQ_FixMS(g)	$VMS_{g \in gnt} = 0$
EQ_HFMS(f,h)	$HFMS_{f \in ft,h} = HFSUP_{f,h} - \sum_{g \in gp} FD_{g,f,h}$
EQ_VFMS(f)	$VFMS_{f \in ft} = \sum_h HFMS_{f,h}$
EQ_FixF(g,f,h)	$(FD_{g,f,h})_{f \in fx} = fd0_{g,f,h}$
EQ_FixHF(f,h)	$(HFMS_{f,h})_{f \in fth,h} = 0$
EQ_FixVF(f)	$(VFMS_f)_{f \in ftv} = 0$
EQ_HFSUP(f,h)	$(HFSUP_{f,h})_{f \in ft} = \left[(Wfth_{f,h})_{f \in fth} + (Wftv_f)_{f \in ftv}\right]^{hfsupel_{f,h}} * endow0_{f,h}$

Full Model Statement – Part 3

Name	Equation
EQ_Fish_Comp(g)	$QPComp_{g\in gcom} = a_g\left[\delta_g\left(TQDForComp^{\rho_g}_{\text{nsfish}}\right) + \left(1-\delta_g\right)\left(TQDForComp^{\rho_g}_{\text{osfish}}\right)\right]^{\frac{1}{\rho_g}}$
EQ_TQDForComp(g)	$TQDForComp_{g\in gin} = \left[\sum_h QP_{\text{nsfish},h} * \left(\frac{P_g}{P_{\text{nsfish}}}\frac{\delta_{\text{fish}}}{\left(1-\delta_{\text{fish}}\right)}\right)^{\frac{1}{\left(\rho_{\text{fish}}-1\right)}}\right]_{g\in gt} + \left[\sum_h QP_{g,h}\right]_{g\in gnt}$
EQ_PComp (g)	$P_{comp\ g\in gcom} = \frac{P_{\_\text{nsfish}} * TQDForComp_{\text{nsfish}} + P_{\text{osfish}} * TQDForComp_{\text{osfish}}}{QP_g}$
Search Cost	$idsh_{(g,retail,h)_{g\in gstk}} = \frac{d_{g,\text{retail},h}}{B^n_{g,t}}$

Full Model Statement – Part 4

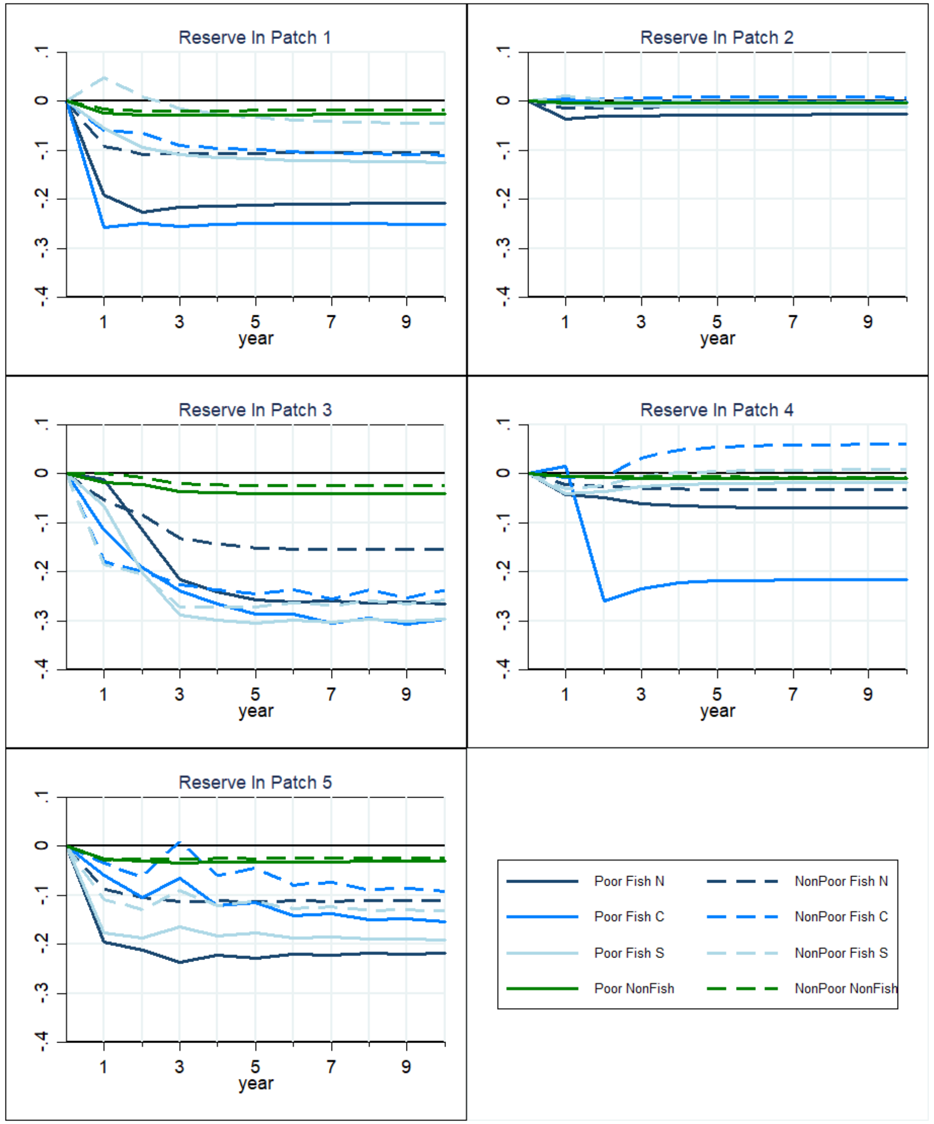
Name	Equation
Nearshore fish stock biological growth	$$\widetilde{B_{\text{nsfish},t+1}} = \omega Rrct_{\text{nsfish},t+1} + SB_{\text{nsfish},t} + pS\left[B_{\text{nsfish},t} - S\left(B_{\text{nsfish},t-1} - \frac{B_{\text{nsfish},t-1}}{\widetilde{B_{\text{nsfish},t}}}\sum_h QP_{\text{nsfish},h,t-1} * KiloCov_{\text{nsfish}}\right) - \omega_{-1}\left(R_{\text{nsfish},t} - \frac{Rrct_{\text{nsfish},t}}{\widetilde{B_{\text{nsfish},t}}}\sum_h QP_{\text{nsfish},h,t-1} * KiloCov_{\text{nsfish}}\right)\right]$$
Nearshore recruitment	$$Rrct_{\text{nsfish},t+1} = \frac{4\overline{Rrct_{\text{nsfish},0}}\, stpnss B_{\text{nsfish},t}}{\overline{B_{\text{nsfish},o}}(1 - stpnss) + B_{\text{nsfish},t}(5 * stpnss - 1)}$$
Nearshore fish stock updating	$$B_{\text{nsfish},t+1} = \widetilde{B_{\text{nsfish},t+1}} - \sum_h QP_{\text{nsfish},h,t} * KiloCov_{\text{nsfish}}$$
EQ_Fish_Comp(g)	$$QPComp_{g\in gcom} = a_g\left[\delta_g\left(TQDForComp_{\text{nsfish}}^{\rho_g}\right) + \left(1 - \delta_g\right)\left(TQDForComp_{\text{osfish}}^{\rho_g}\right)\right]^{\frac{1}{\rho_g}}$$
EQ_TQDForComp(g)	$$TQDForComp_{g\in gin} = \left[\sum_h QP_{\text{nsfish},h} * \left(\frac{P_g}{P_{\text{nsfish}}}\frac{\delta_{\text{fish}}}{(1 - \delta_{\text{fish}})}\right)^{\frac{1}{(\rho_{\text{fish}} - 1)}}\right]_{g\in gt} + \left[\sum_h QP_{g,h}\right]_{g\in gnt}$$

Back

Impact to Real Incomes
Participation in nearshore fishing

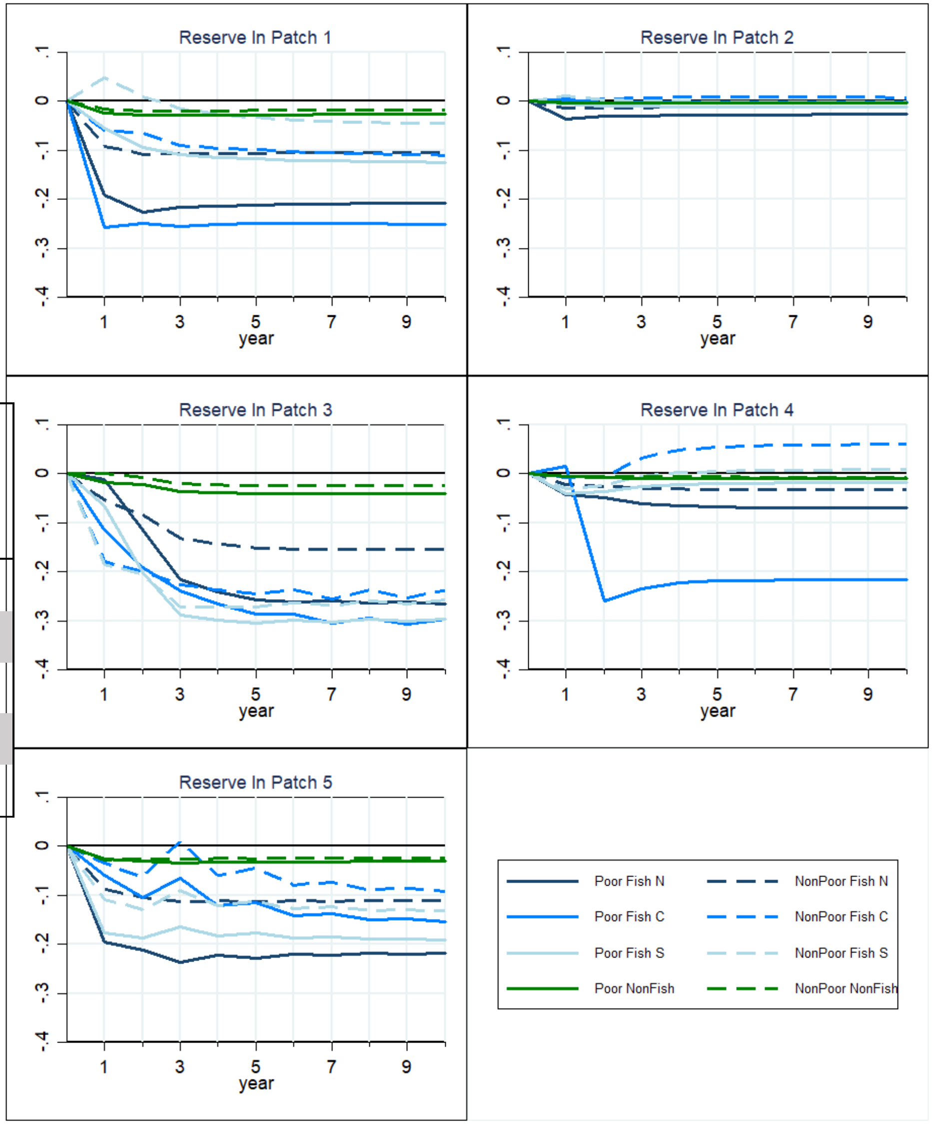
Percentage of harvest from each nearshore fishing patch

	Fishing Households						
	North Poor	**North Non-Poor**	**Central Poor**	**Central Non-Poor**	**South Poor**	**South Non-Poor**	**Total**
Patch 1	95%	95%	70%	70%	1%	1%	18%
Patch 2	1%	1%					0.1%
Patch 3	4%	4%	26%	26%	45%	45%	38%
Patch 4			5%	5%	11%	11%	9%
Patch 5					43%	43%	34%



Back

Impact to Real Incomes
Participation in all production activities



Percentage of capital owned by each representative household

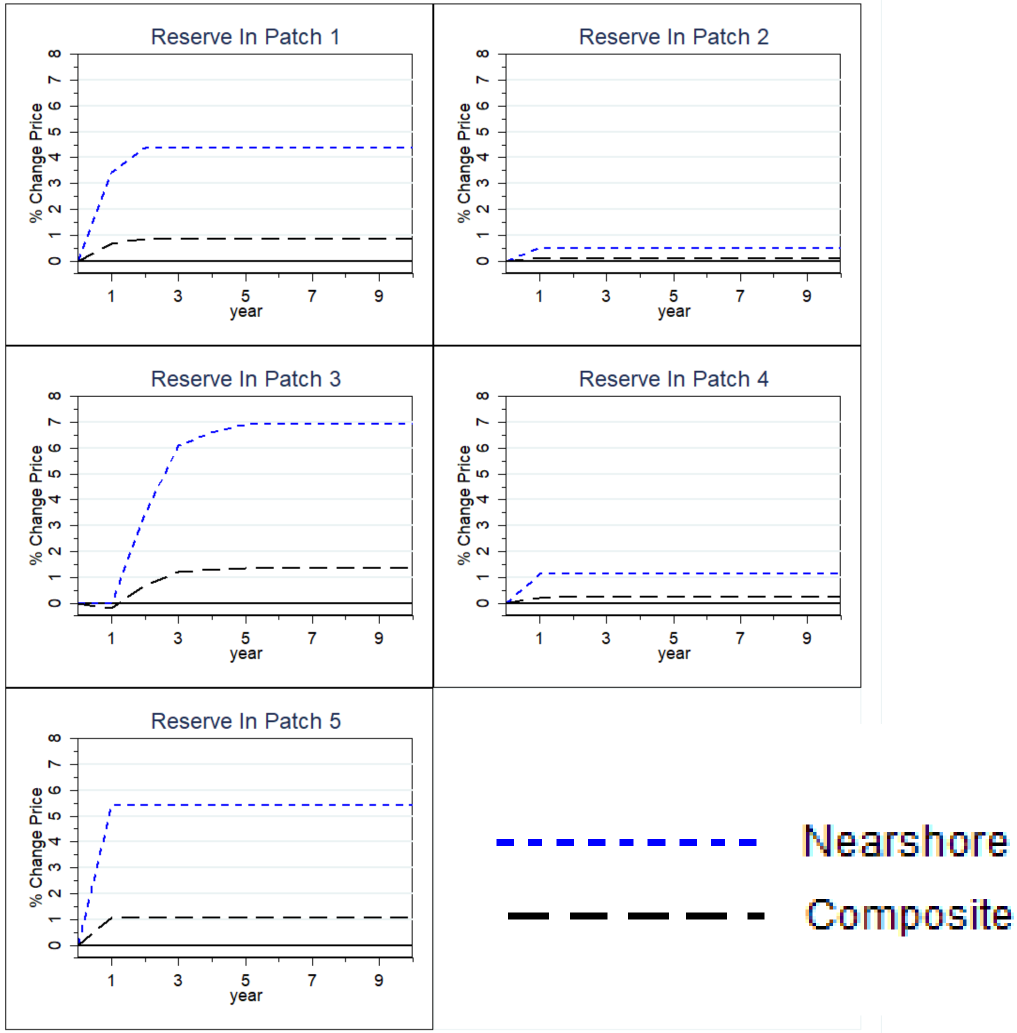
	Fishing Households						Non-Fishing Households	
	Northern Poor	Northern Non-Poor	Central Poor	Central Non-Poor	Southern Poor	Southern Non-Poor	Poor	Non-Poor
Agriculture	0.36%	0.84%	1.29%	1.69%	0.45%	3.64%	10.23%	81.50%
Restaurants				0.06%				99.94%
Retail	0.46%	0.31%		1.08%	0.42%	0.06%	3.70%	93.98%
Other Services		0.01%		0.08%	0.26%	7.96%	20.65%	71.04%
Fishing	18.51%	55.99%	0.31%	1.71%	1.65%	21.82%		

Back

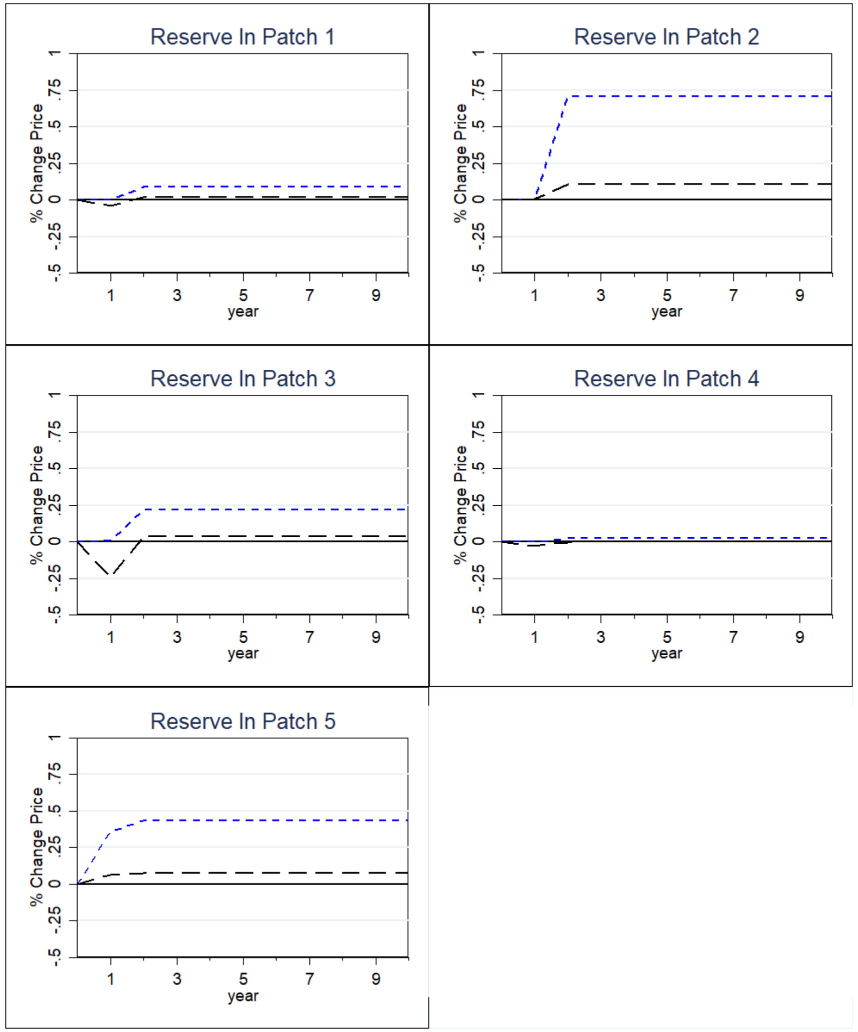
% Change in Fish Price

Increase price of fish sold in local markets

Inelastic substitution



Elastic substitution

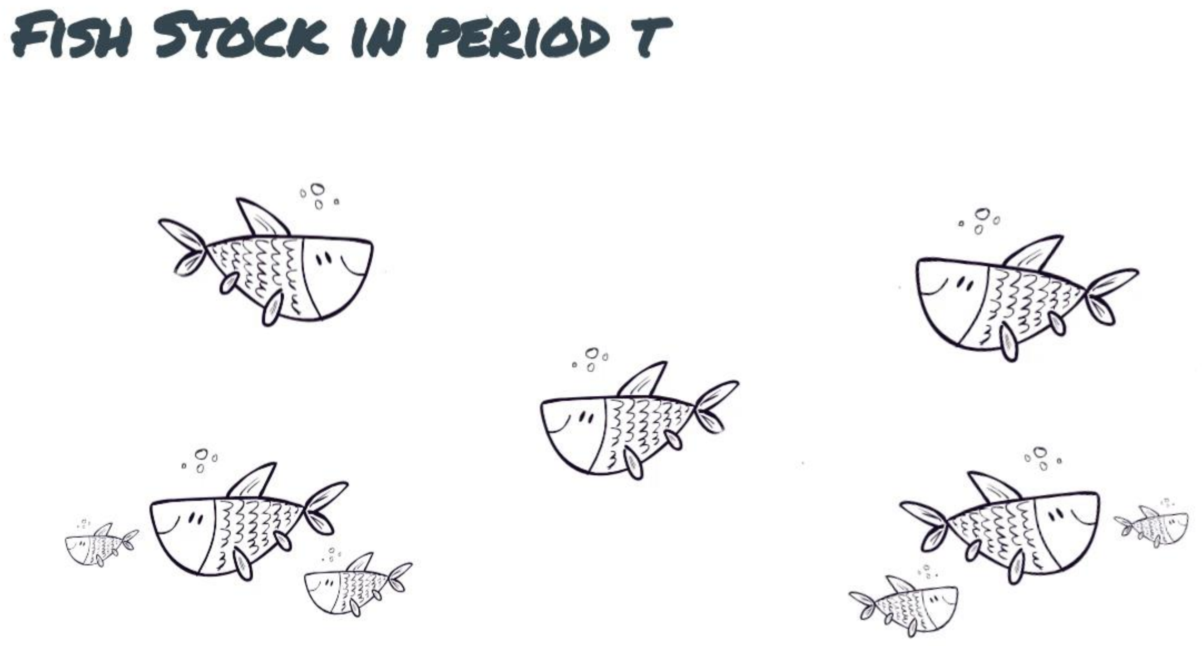


Back

Modeling Framework: Component 2 – Bioeconomic Model

Stylized Deriso-Schnute delay-difference model with Beverton-Holt recruitment

$$\underbrace{X_{Fish,t+1}}_{\text{Updated biomass}} = \underbrace{SX_{Fish,t}}_{\text{Surviving biomass}} + \underbrace{pS\left(X_{Fish,t} - SX_{Fish,t-1} - \omega_{-1}R_{Fish,t}\right) + \omega R_{Fish,t+1}}_{\text{Growth of surviving biomass and recruit of new adults}} - \underbrace{f_{Fish}(Inputs_t, X_{Fish,t})}_{\text{Harvest}}$$



Biological Parameters: Characterizing Fish Stocks

Average Species

- *Lethrinus miniatus* – Trumpet emperor
- h = 0.7, p = 0.29, S = 0.56

Vulnerable Species:

- *Lutjanus malabricus* - Saddletail Snapper
- h = 0.5, p = 0.18, S = 0.90

Robust Species:

- *Balistes vetula* – Queen Triggerfish
- h = 0.9, p = 0.57, S = 0.07

Parameters
S = Natural Survival Rate
p = Brody growth coefficient
h = steepness parameter in larvae recruitment function

Back

Modeling Framework: Connecting Component 1 & Component 2

Component 1: **Period t**
Holding fish stock constant $X_{Fish,t}$
Solve local general equilibrium model
(equilibrium in period t solution found)

Open Access Fishery: Fishermen make harvest decisions without considering impacts to other fishermen or future stock

→over allocate capital & labor to fishing activities

Calculate harvest
Function of inputs and stock level

Component 2: Update Biomass
solve for new fish stock $X_{Fish,t+1}$
account for survival, growth, and harvest

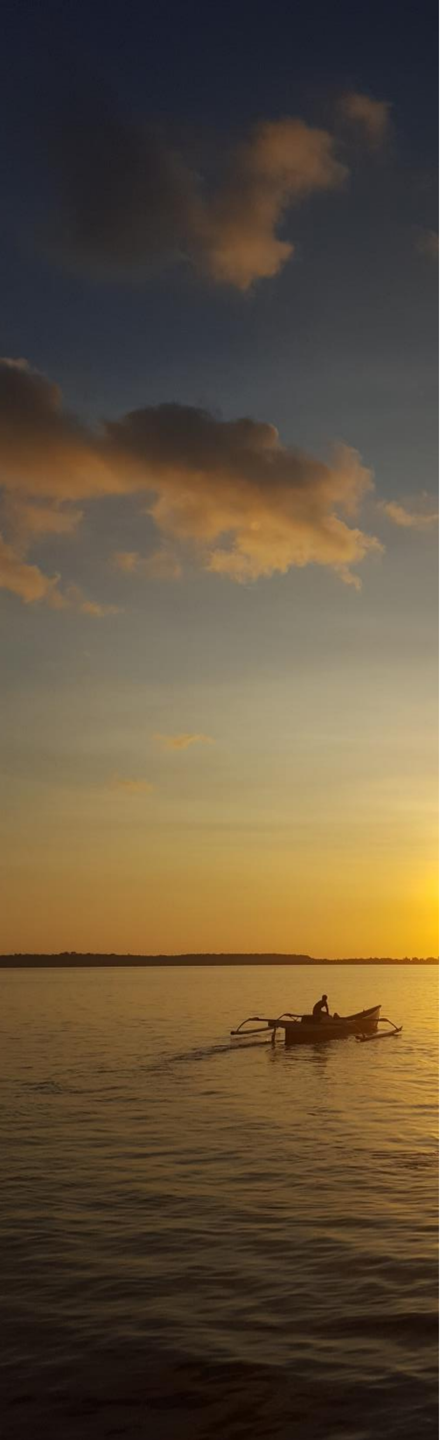
***New** fish stock*

Component 1: **Period t + 1**
Holding *new* fish stock constant $X_{Fish,t+1}$
Solve local general equilibrium model
(equilibrium in period t solution found)

Calculate harvest
Function of inputs and stock level

Component 2: Updat
solve for new fish stock $X_{Fish,t}$
account for survival, growth, a

Back



Household fishing trips

- Average fishing trip length: 25.5 hours (Median: 7)
- Average fishing trip frequency: 15 trips per month (Median: 15)
- Average # of fishermen per trip: 3 (Median: 1)
- Most (90%) fishing trips described occurred in a single habitat type

	Offshore Fishing	**Nearshore Fishing**
Fishing Gear	- Pole and Line - Long Line - Nets	- Pole and Line - Spears - Nets
Habitats	- Pelagic	- Coral Reef - Sea Grass - Mangrove
Fish Harvested	- Tuna - Mackerel - Jacks & Trevallies	- Grouper - Snapper - Emperors - Fusiliers - Squid - Parrotfish - Triggerfish - Surgeonfish - Rabbitfish - Crab & Lobster

Fishing vessels used in each of the fishing trips

Decreasing Vessel Size →

	Kapal	Jolloro	Jarangka	Sampan
Offshore Trip	45%	14%	35%	14%
Nearshore Trip	3%	20%	25%	42%

Types of Fishing Vessels

Type of Vessel	Average Length (in meters)	Percentage with Engines*	Average Number Engines**	Average Size of Main Engine (in hp)**
Kapal	16.4	100%	2.6	70.1
Jolloro	10.6	100%	1.9	36.0
Jarangka	5.9	95.74%	1.1	7.4
Sampan	4.3	57.58%	1.0	6.1

*Percentage of all reported vessels with at least one engine

**Average from all reported vessels with at least one engine

Kapal

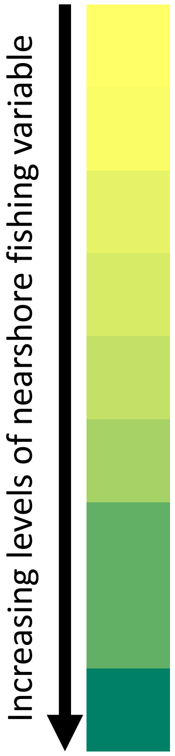
Jolloro

Jarangka

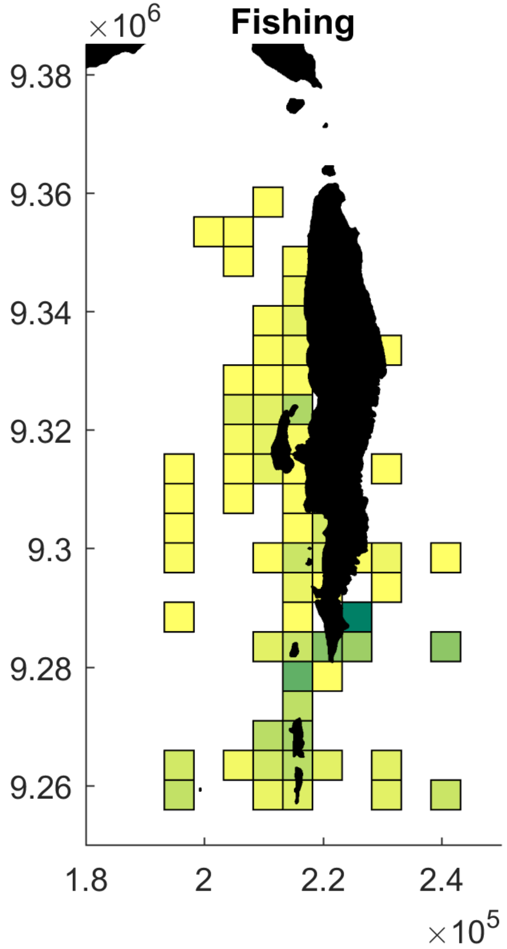
Sampan

Back

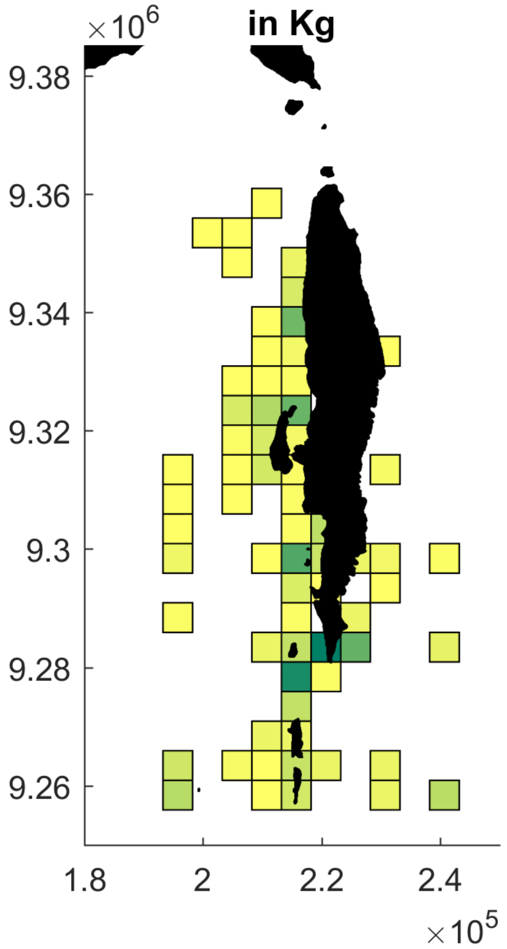
Spatial Distribution of Nearshore Fishing (From survey data)



Nearshore Trips Total Person Hours Fishing

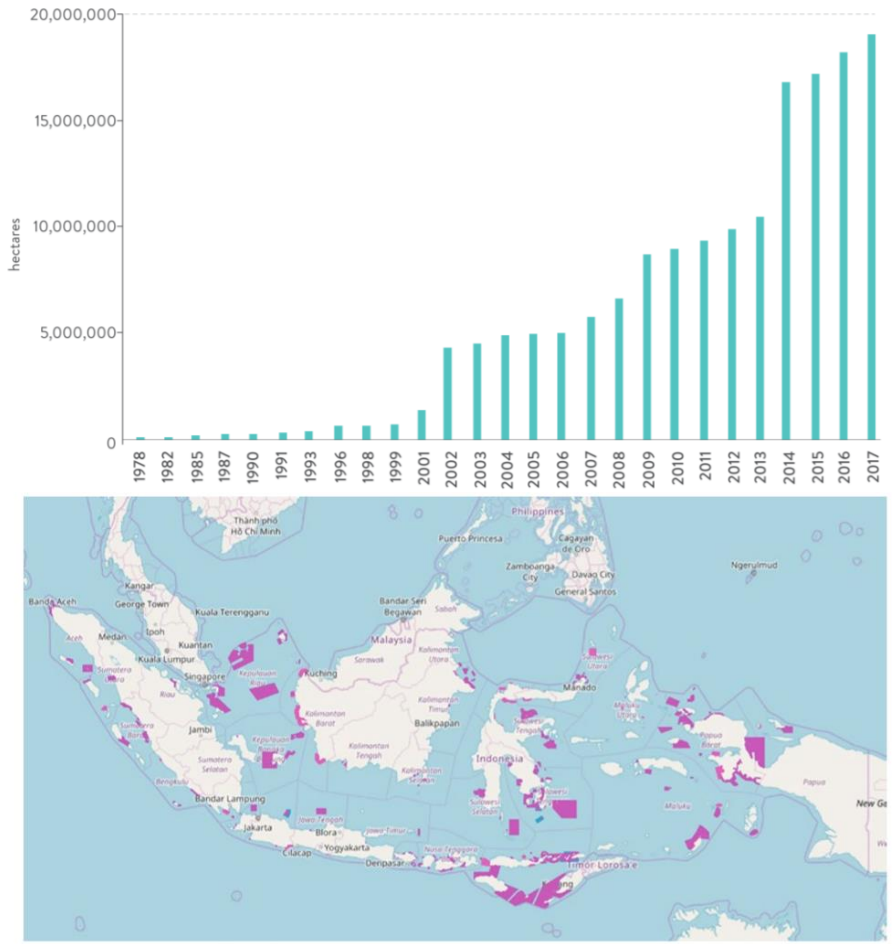


Nearshore Trips Total Harvest in Kg



Indonesia’s growing commitment to & interest in marine reserves

- Coral Triangle Initiative Summit (2009)
    - Commitment to protect 20 million hectares by 2020
- The current presidential administration (since 2014) has prioritized management and development of marine fisheries
- By 2017, 19.14 million hectors of MPAs have been set aside (according to the MMAF)
    - 20% of nearshore waters within 10 miles of coastline are under some form of marine protection
- Rapid expansion of MPAs has not been met with a parallel increase in regulatory and budgetary capacity



(Top) There has been a steady increase in the area designated for MPAs in Indonesia. (Bottom) Location of MPAs as of 2017.
Source – Trends in Marine Resources and Fisheries Management in Indonesia: A 2018 Review (CEA)

Back

Marine Capture Fisheries in Indonesia

Are MPAs a way to sustainably manage fisheries?

Fisheries are an important contributor to food security and income generation

- Wild capture fisheries employ 2.7 million workers
- + over 1 million employed in processing & marketing

Indonesia is the 2nd largest producer of marine capture fish

- Majority of fishers are small-scale fishermen

(work without a vessel or with a vessel ≤ 10 Gross Tons)

> Household producers are important contributors to & users of Indonesia's marine fisheries harvests

COUNTRY	FISH-DERIVED ANIMAL PROTEIN
Maldives	70.87%
Cambodia	68.71%
Sierra Leone	64.36%
Kirbati	62.46%
Solomon Islands	59.13%
Sri Lanka	55.30%
Bangladesh	54.13%
Indonesia	52.68%
Ghana	49.94%
Gambia	49.01%

Top 10 Fish-Dependent Nations, measured in % of Animal-Source Protein derived from fish