Feasibility of commercial-scale mesopelagic fisheries and impacts on pelagic fisheries and fishmeal markets

Melina Kourantidou

AMURE, Université de Bretagne Occidentale
Marine Policy Center, Woods Hole Oceanographic Institution

Brest, 18th January 2024

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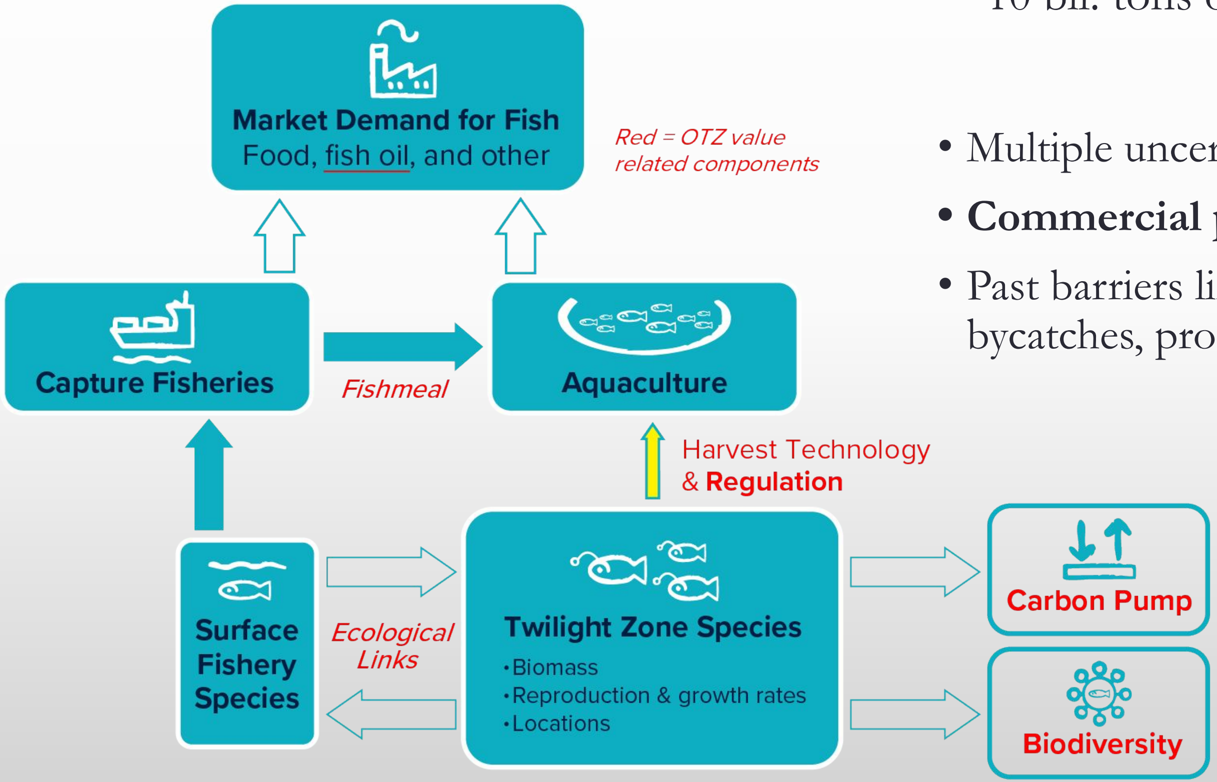
- Kourantidou, M., & Jin, D. (2022). **Mesopelagic–epipelagic fish** nexus in **viability and feasibility of commercial‐scale mesopelagic fisheries**. Natural Resource Modeling, 35(4), e12350.

- Quang, R. G. T., Kourantidou, M. Jin, D. (2024). Assessing the **potential economic effects** of **mesopelagic fisheries** as a **novel source** of **fishmeal**. Natural Resource Modelling *(in review)*.

Impacts of fishing the Twilight Zone



Ocean waters 100 - 1000m

~ 10 bil. tons of fish ~90% of all ocean fish

- Multiple uncertainties on **ecosystem role & value**
- **Commercial potential** poorly understood
- Past barriers limiting profitability: catch efficiency, bycatches, processing

Key in the **food chain** & **carbon sequestration**

Lanternfish (Myctophidae): important prey (dolphins, sharks, whales, billfish, rays, bigeye & yellowfin tuna)

Bioeconomic model to assess **trade-offs** from **interactions** with **surface living predator fish**

- Epipelagic x
- Mesopelagic y

$$F(x,y) = rx\left(1 - \frac{x}{K}\right) + \alpha xy$$

$$G(x,y) = sy\left(1 - \frac{y}{L}\right) + \beta xy$$

- $\alpha = 0, \beta = 0$ Neutralism (Independent)
- $\alpha > 0, \beta > 0$ Mutualism
- $\alpha < 0, \beta < 0$ Competition
- $\alpha > 0, \beta < 0$ or $\alpha < 0$ & $\beta > 0$ Prey - Predation (Parasitism)
- $\alpha > 0, \beta = 0$ or $\alpha=0, \beta > 0$ Commensalism

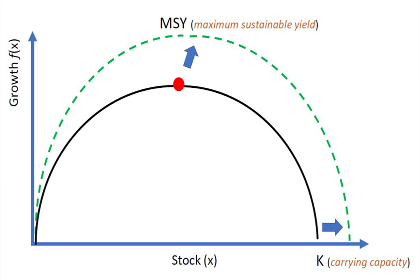
$$h_1 = q_1 E_1 x \qquad h_2 = q_2 E_2 y$$

$$\max_{h_x, h_y} PV = \int_0^\infty \{[p_x - c_x(x)]h_1(t) + [p_y - c_y(y)]h_2(t)\} e^{-\delta t} dt$$

$$\Pi(x,y) = [p_x - c_x(x)]F(x,y) + [p_y - c_y(y)]G(x,y)$$

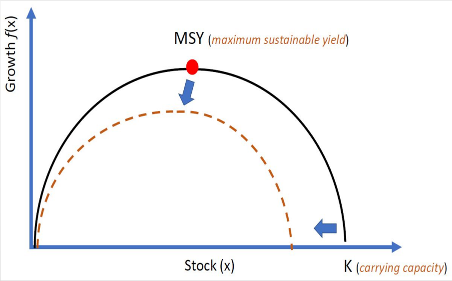
Epipelagic X   Mesopelagic Y

Logistic Growth Curves



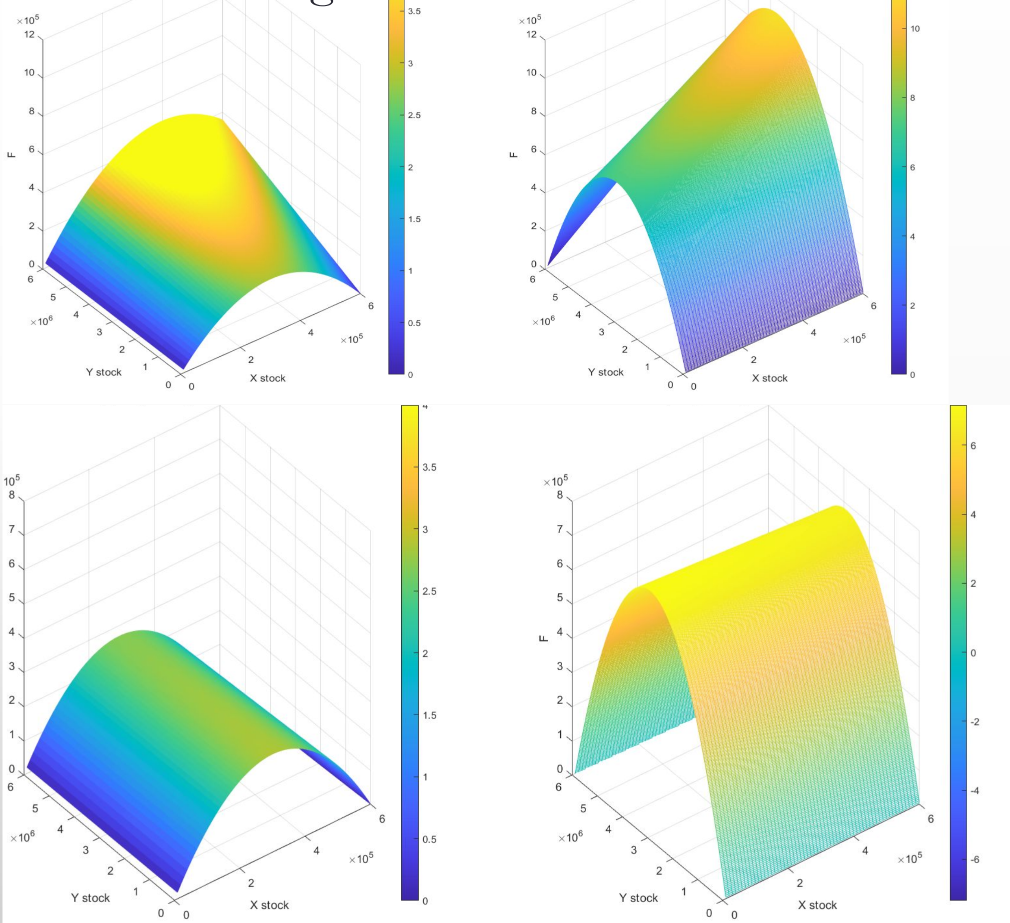
Mutualism

$\alpha > 0, \beta > 0$



Competition

$\alpha < 0, \beta < 0$



Assumptions & Model parameters

- Price $p_x > p_y$
- Cost $c_x < c_y$
- Catchability $q_x > q_y$
- Carrying Capacity $K < L$
- Intrinsic Growth rate $r > s$

Silvery lightfish, *Maurolicus muelleri,* SAPFIA

Dana Lanternfish, *Diaphus danae*. Source: T. Carter / CSIRO

Bigeye Tuna, *Thunnus obesus* Source: Fishpix / Fishes of Australia

Economic feasibility

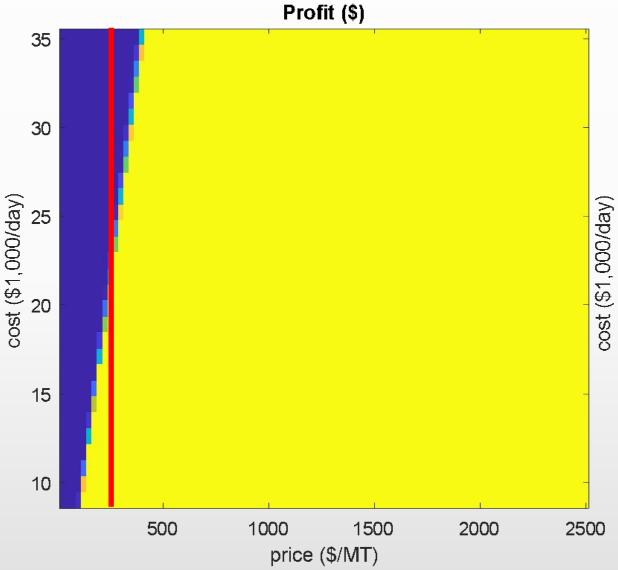
$9,000 – $35,100/day

Higher cost

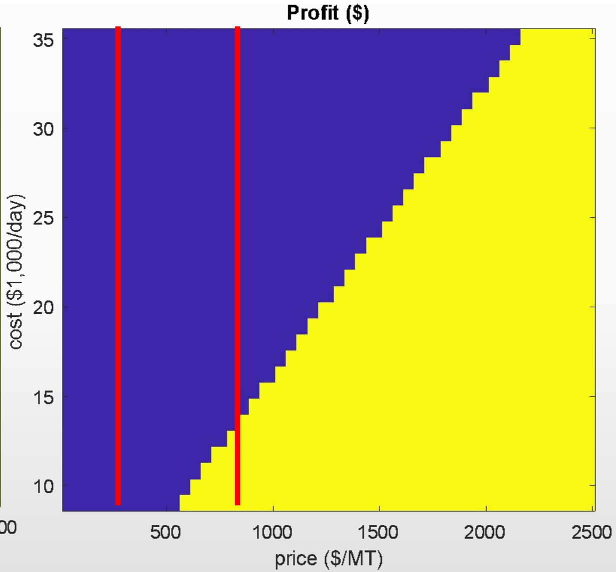
Non-Feasible $\Pi < 0$

Feasible $\Pi > 0$

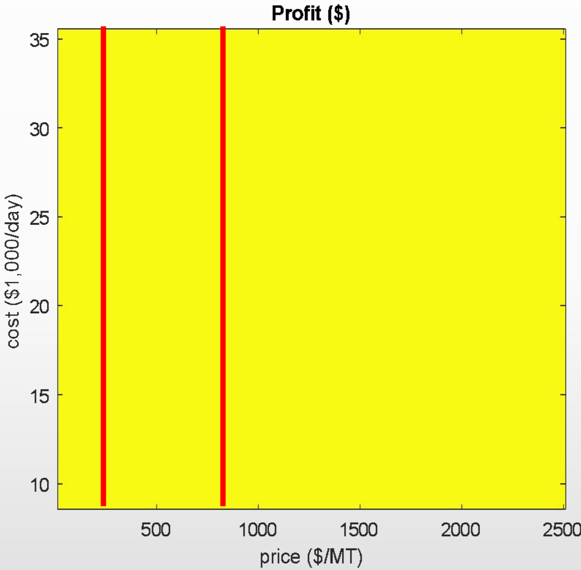
Neutralism



Mutualism



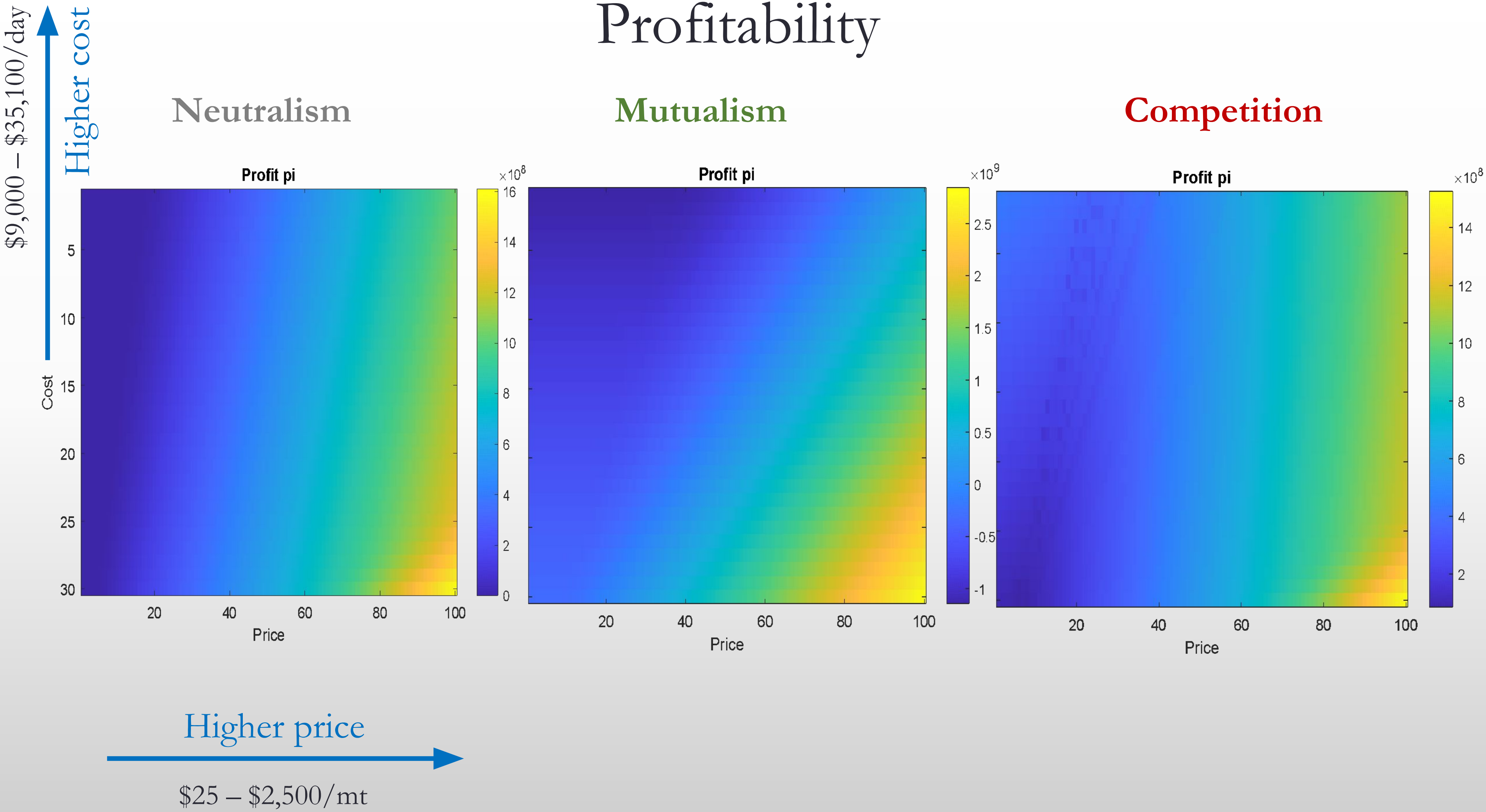
Competition

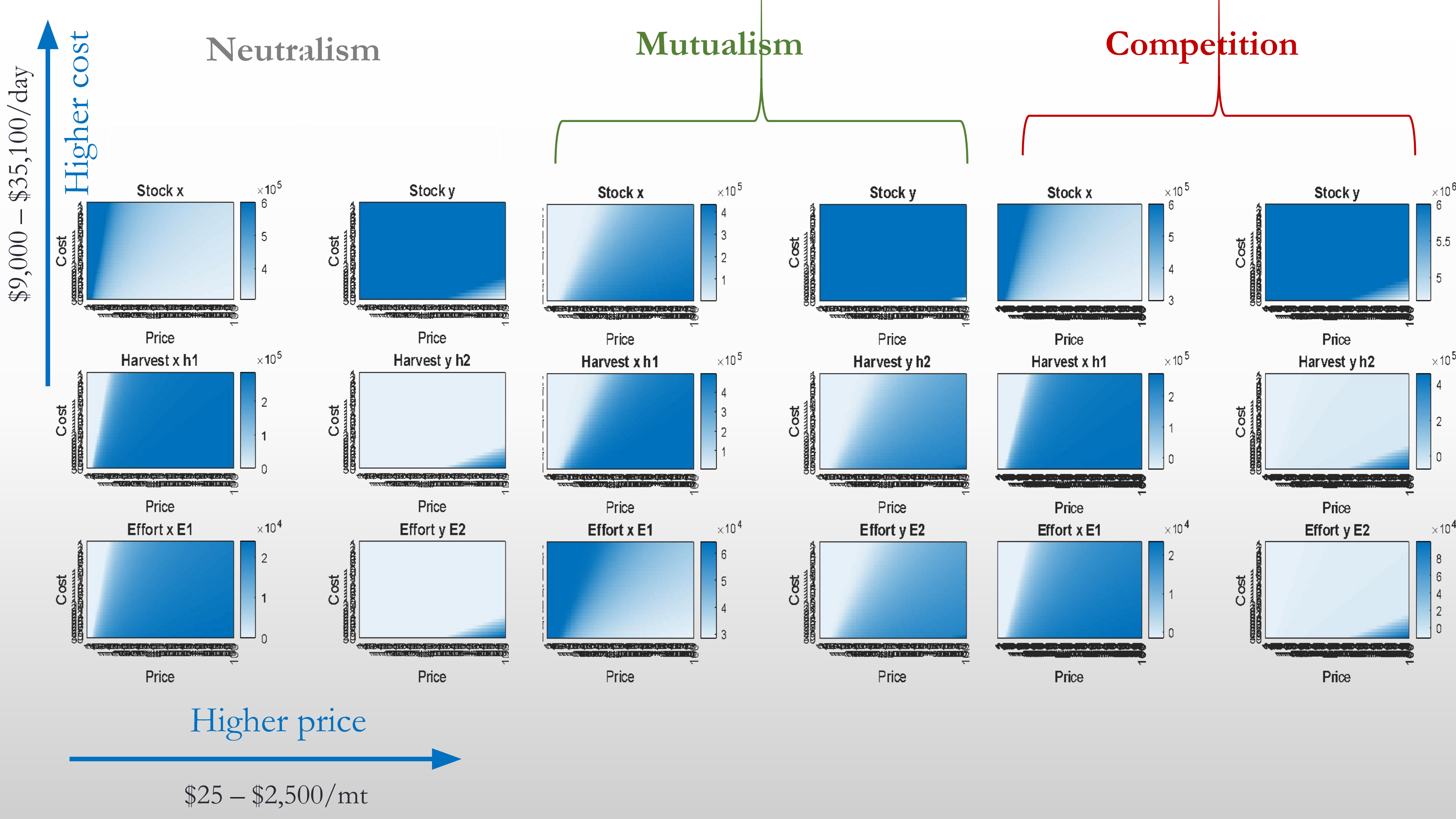


Higher price

$25 – $2,500/mt

Profitability

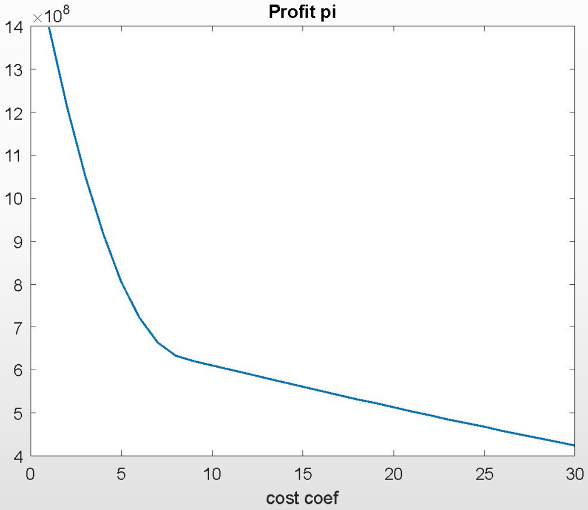




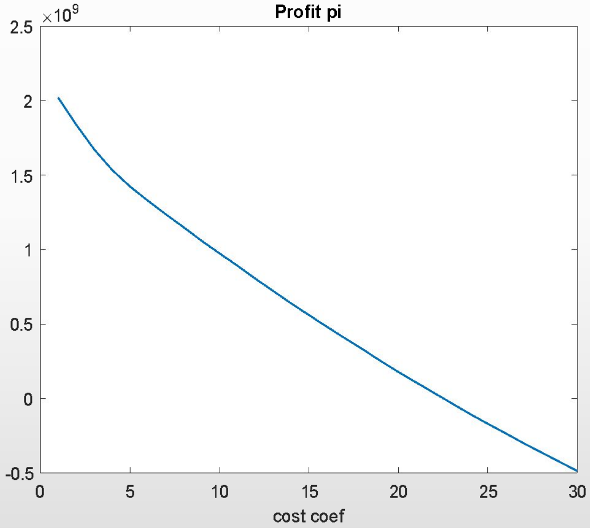
Neutralism
Mutualism
Competition
Higher cost
$9,000 – $35,100/day
Stock x
Stock y
Harvest x h1
Harvest y h2
Effort x E1
Effort y E2
Cost
Price
Higher price
$25 – $2,500/mt

Profit Sensitivity w.r.t. Cost

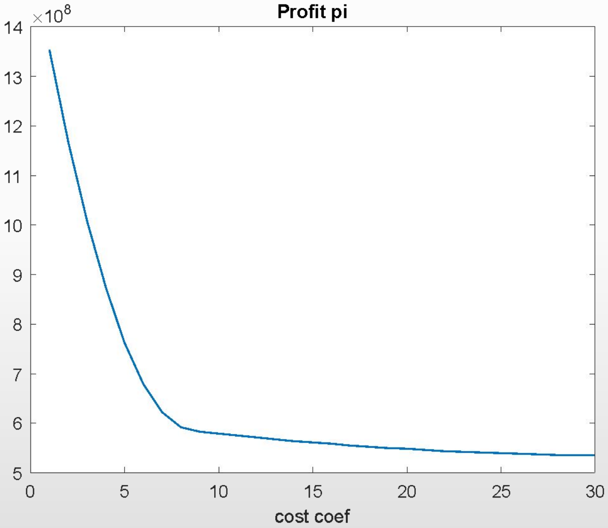
Neutralism



Mutualism



Competition

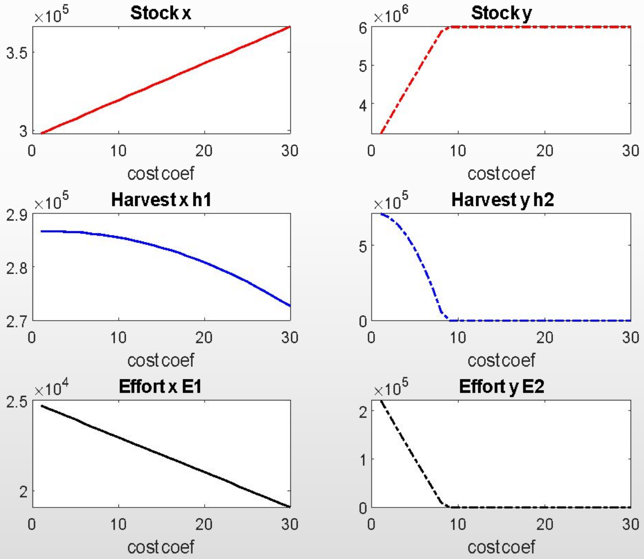


Higher cost →

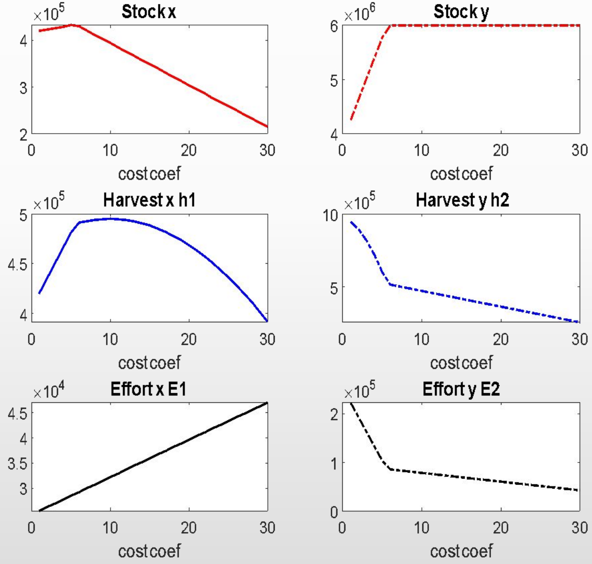
$9,000 – $35,100/day

Sensitivity w.r.t Cost

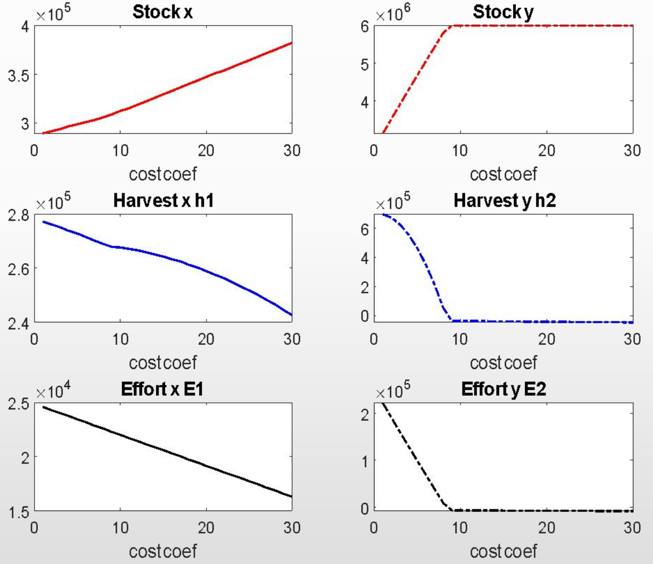
Neutralism



Mutualism



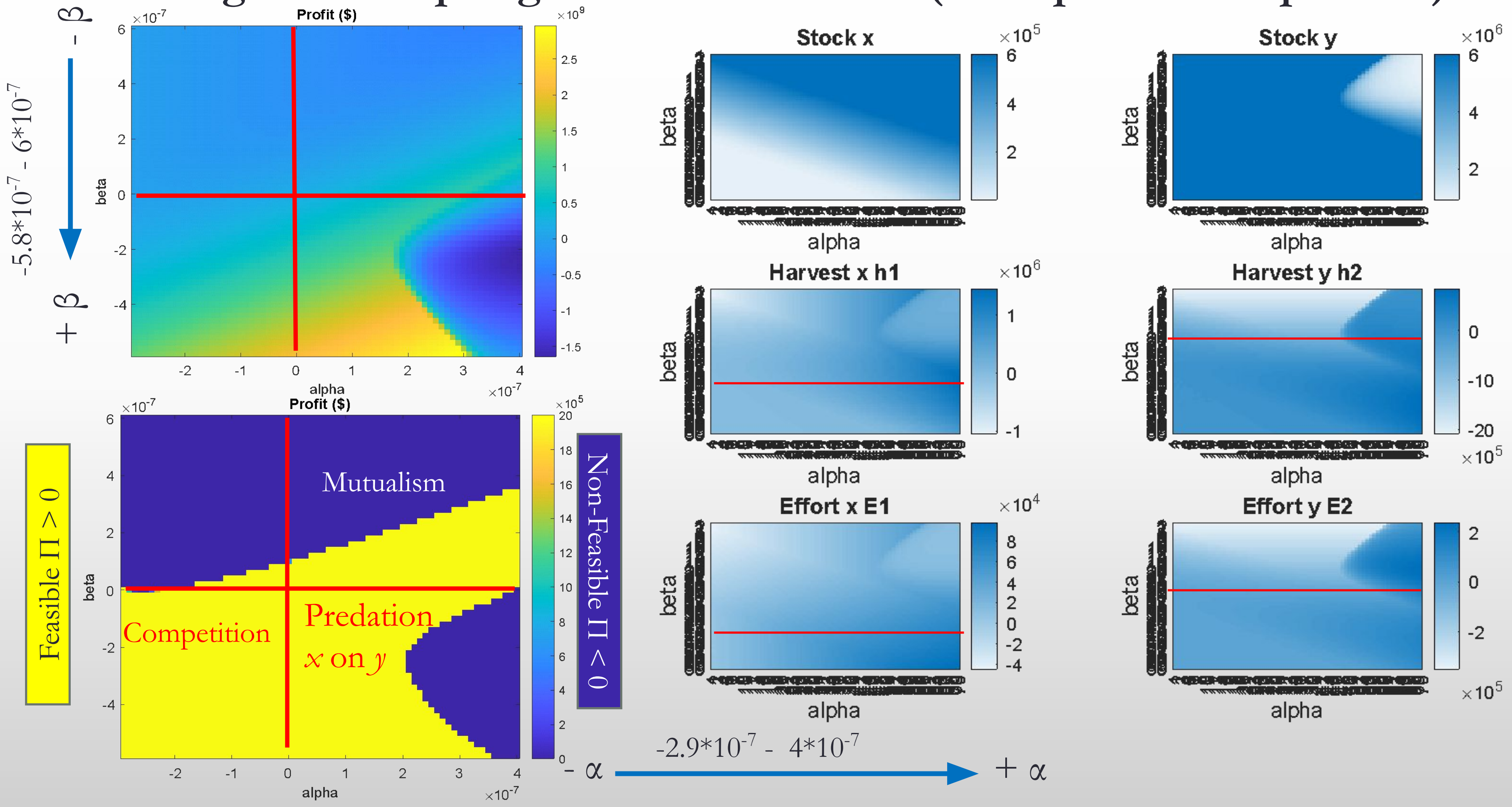
Competition



Higher cost

\$9,000 – \$35,100/day

Pelagic – Mesopelagic stock interaction (interspecific competition)



So far

- **Ecological uncertainties** persist

- How do mesopelagic fish **interact** with other valuable pelagic fish?

- Under what **conditions** does it **make economic sense** to **harvest** the **mesopelagic**?

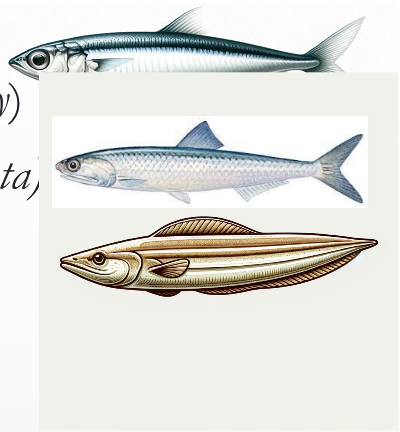
- **Trade-offs** indicating the importance of understanding ecological & biological details

- Informing **policies** & efforts to **protect** mesopelagic fish & **design proactive actions**

Mesopelagic fish as a **new fishmeal source**

3 major forage-fish fisheries
(~70% global fishmeal)

- **Asia** (Vietnam, China, and Thailand, *Japanese anchovy*)
- **Humboldt Current** (Peru & Chile, *Peruvian anchoveta*)
- **Europe** (Norway and EU, *North Sea sandeel*)



- How ?
  - **economic linkages** between **fishmeal production systems**
  - simulations - bioeconomic model: how **pelagic fishmeal production responds** to **inclusion** of hypothetical, economically-viable **mesopelagic fisheries** (*Merino et al., 2010 extension*)

Merino, G. et al., (2012). Can marine fisheries and aquaculture meet fish demand from a growing human population in a changing climate? Global Environmental Change, 22(4), 795–806.

Population Dynamics & Fishmeal market

- $$X_i(t+1) = X_i(t) + r_i X_i(t)\left(1 - \frac{X_i(t)}{K_i}\right) - Y_i(t)$$
- i 4 production systems
- $X_i(t)$ stock in fishery i and year t
- Y harvest

$$Quota_i(t) = Y_{MSY_i} = \frac{r_i K_i}{4}$$

p fishmeal price
α choke price
β slope of demand curve;
Q aggregate fishmeal quantity supplied to market (sum of supplies from different fishmeal production systems)
λ yield-to-meal transformation ratio.

$$p(t) = \alpha - \beta Q(t)$$

$$Q(t) = \sum_{i=1}^{4} Q_i$$

$$Q_i(t) = \lambda_i Y_i$$

Production systems links - equilibrium

$$R_i(t) = \lambda_i p(t) Y_i(t) - f_i E_i(t) - r_i Y_i(t) - s_i d_i Q_i(t)$$

(R) net profit for each fishmeal production system

f unit cost of fishing effort

r cost of reducing fish into fishmeal

s cost of shipping fishmeal to international markets

d distance to main consumers

$$E_i(t+1) = E_i(t) + j_i\left(\frac{R_i(t)}{v_i}\right)$$

v price of a new fishing unit

j coefficient controlling investment in additional fishing effort

$$Q_{MSY} = \sum_{i=1}^{4} \lambda_i Y_{MSYi}$$

$$p_{MSY} = \alpha - \beta Q_{MSY}$$

Data & Parameters: Fishmeal Production (10^3 t/year)

Year	Humboldt		Asia			Europe	
	Peru	Chile	Vietnam	China	Thailand	Norway	EU
2014	754	450	423	450	450	200	455
2015	660	450	450	400	480	204	480
2016	972	435	435	436	350	210	466
2017	1000	368	450	400	335	230	420
2018	1068	345	470	364	340	220	435
2019	910	410	460	350	335	230	405
2020	1169	370	450	350	340	230	400
2021	1150	369	530	365	350	220	400
2022	1100	369	440	400	340	230	400
2023	1100	375	500	430	370	230	400
Country Mean	988.3	394.1	460.8	394.5	359	220.4	426.1
Regional Mean		1382.4			1214.3		646.5

Source: IndexMundi compilation of U.S. Department of Agriculture data

Variable	Description	Humboldt ($i = 1$)	Asia ($i = 2$)	Europe ($i = 3$)	Mesopelagic (4)
$Q_i(0)$	Initial fishmeal production (Mt year^{-1})	1.38	1.21	0	0.004
$Y_i(0)$	Initial fish production Mt year^{-1}	6.00	2.68	2	0.02
K_i	Carrying capacity (Mt)	49.99	18.95		100
$X_i(0)$	Initial fish stock (Mt)	18.5	9.47		100
r_i	Intrinsic growth rate (y^{-1})	1	0.5	0.9	.478
q_i	Catchability coefficient (10^{-6} fu^{-1})	1.5	1.42	1	1
$E_i(0)$	Initial fishing effort (m^3)	63206	58052	425	5000
$Emax_i$	Max fishing effort (m^3)	200000	55000	500	0000
cf_i	Fishing costs ($ fu^{-1})	65	65	103	105
v_i	Price of increasing fishing capacity ($ m^{-3})	2600	2860	5850	6500
cr_i	Fishmeal transformation costs ($ t^{-1})	130	260	294.71	260
cs_i	Shipping costs ($ t^{-1} km^{-1})	0.026	0.026	0.026	.026
$dist_i$	Distance to consumer (km)	13000	500	500	600
j_i	Fleet investment coefficient	0.2	0.2	0.2	0.2
a	Choke fishmeal price ($ t^{-1})			1700	
β	Slope of demand curve($ t^{-2})			60	

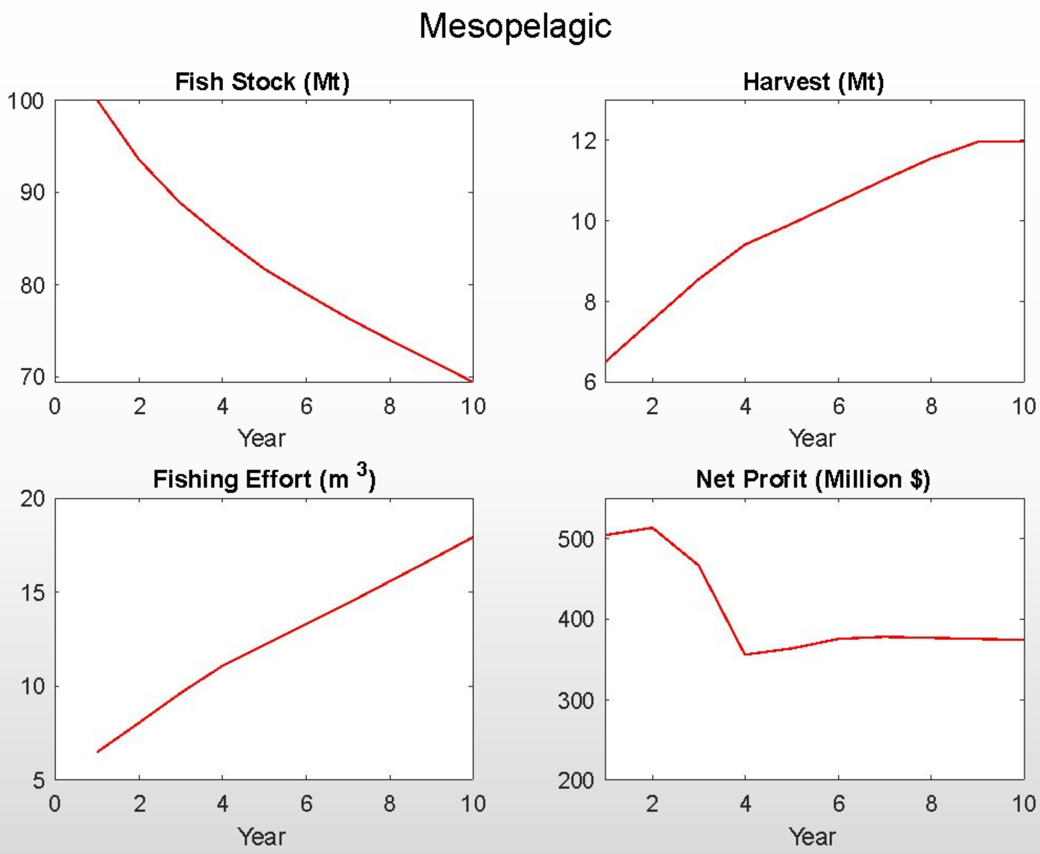

pearlside


Lanternfish

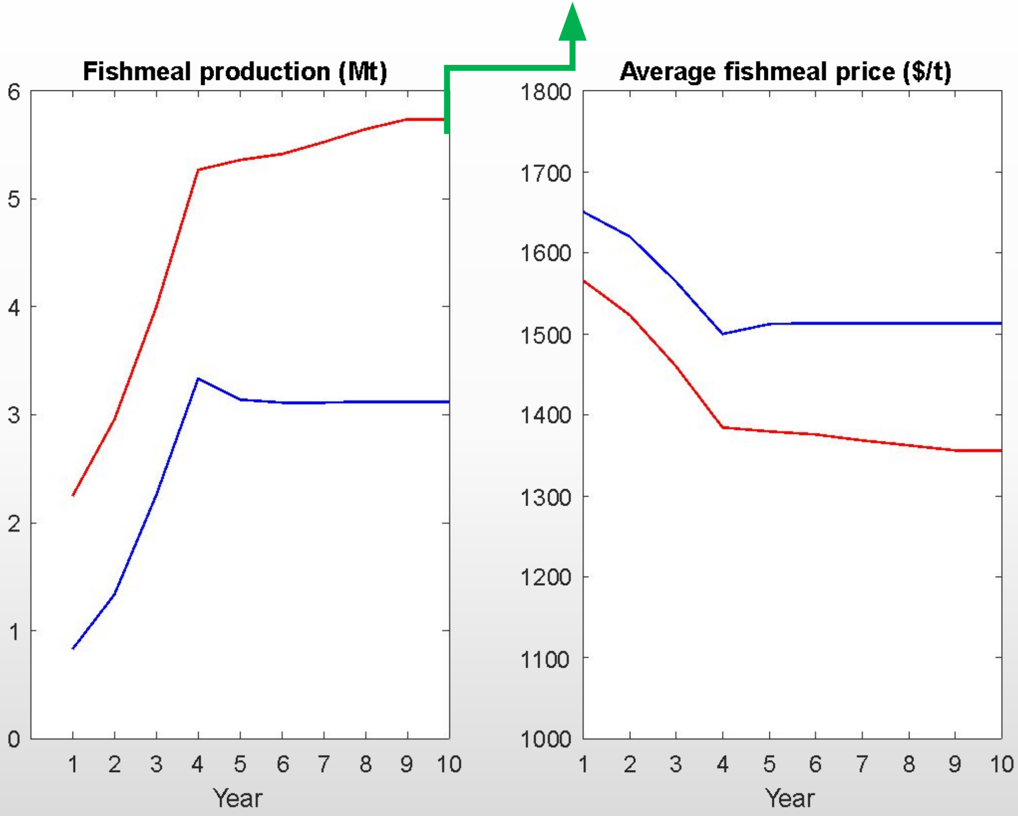
Results

Unprofitable mesopelagic FM production if FM transformation cost ≈ **European** production system ($294.71/t)

Feasible mesopelagic FM production if FM transformation cost ≈ **Asian** production system ($260/t)

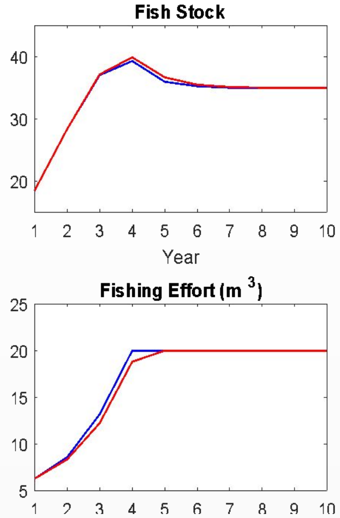


5.74 Mt – global FM supply meets projected production by 2031 (OECD & FAO, 2022)



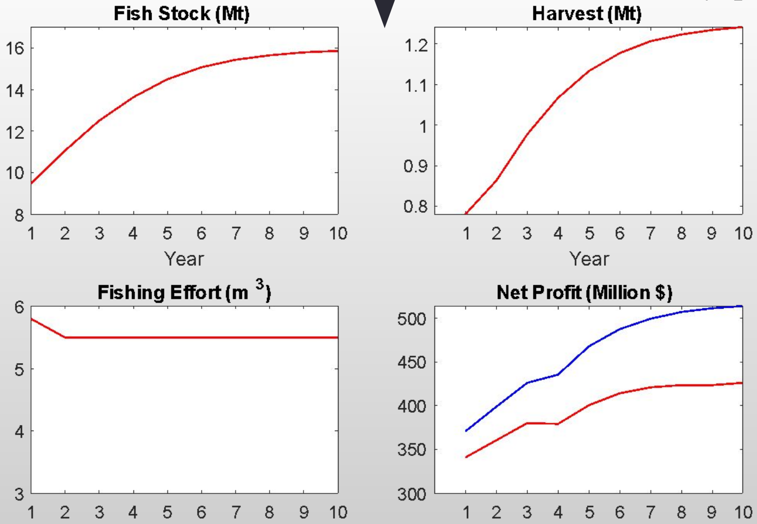
Scenario 1: W/o mesopelagic

Scenario 2: W mesopelagic

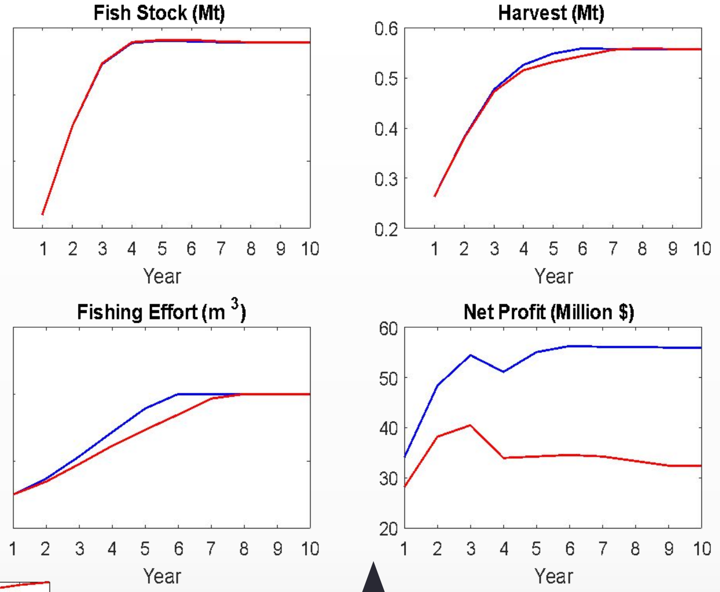


Humboldt

Asia



Europe



Scenario 1: W/o mesopelagic

Scenario 2: W mesopelagic

Conclusions & Outlook

- Sourcing FM from global mesopelagic stock **possibly profitable** for **mesopelagic harvesters**
- **Reduction in FM price** makes it more econ-viable feed source for Aquaculture
- But ! Lower price -> **profit reductions for existing** forage fish production
- Adding the mesopelagic: Opportunity & Environmental risk

Other considerations

- Going beyond the regions assessed and encompassing the global fishmeal production (beyond the ~70% captured here)
- Biological and ecosystem interactions
- spatial use conflict
- climate variations

Thank you!

Barrel shrimp
(Phronima sp.)

Fangtooth
(Anoplogaster cornuta)

Enoploteuthidae

Bristlemouth
(Sigmops bathyphilus)

Black dragonfish
(Idiacanthus fasciola)

Sensitivity to future demand: Global FM price at steady state under different demand parameters.

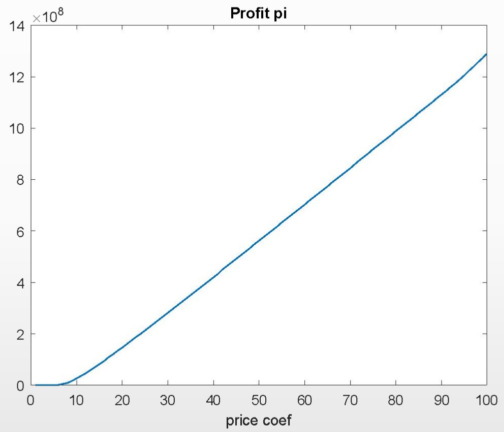
Scenario	a	β		
		60	120	180
1	1700	1,438	1,175	913
2		1,281	862	443
Change		10.90%	26.70%	51.50%
1	2100	1,838	1,575	1,313
2		1,681	1,262	843
Change		8.50%	19.90%	35.80%
1	2500	2,238	1,975	1,713
2		2,081	1,662	1,243
Change		7.00%	15.90%	27.40%

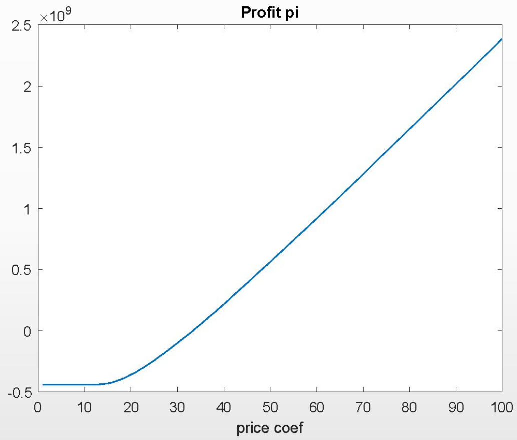
Sensitivity w.r.t. Price

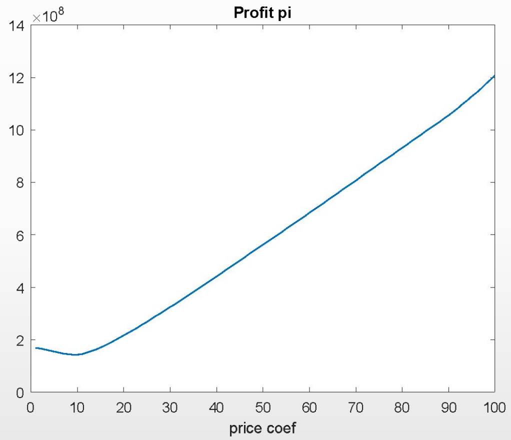
Neutralism

Mutualism

Competition



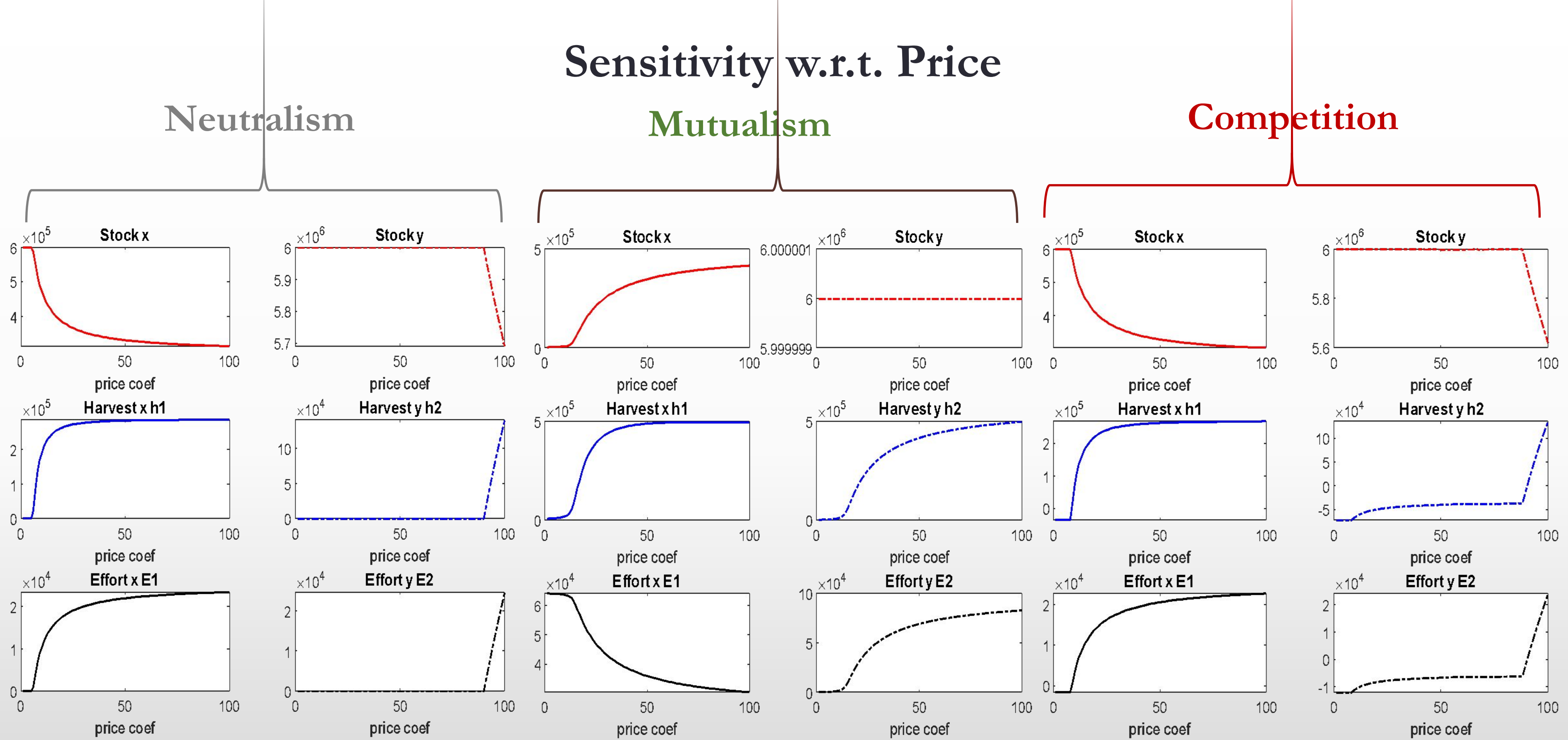




Higher price

$25 – $2,500/mt

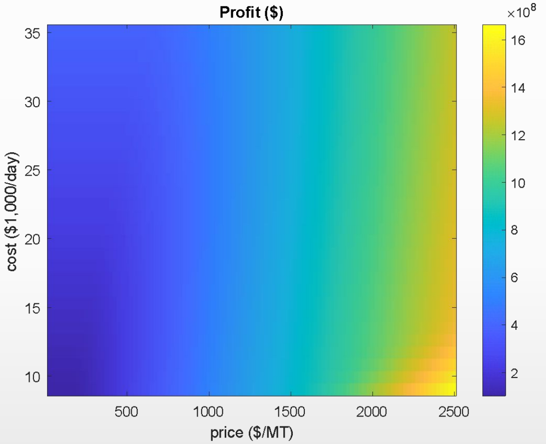
Sensitivity w.r.t. Price

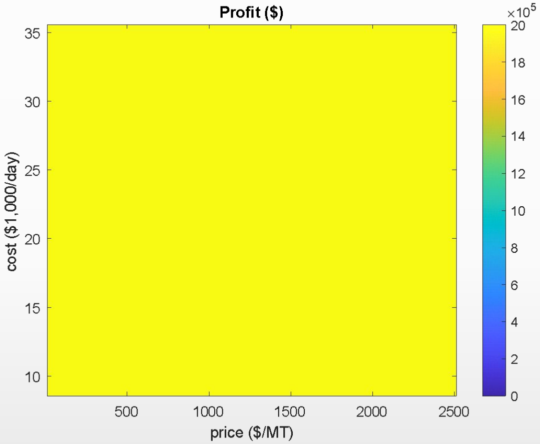


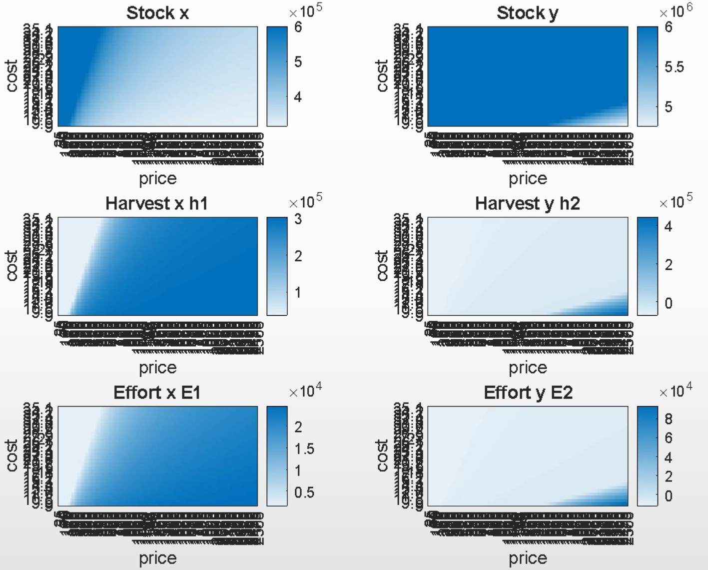
Higher price

$25 – $2,500/mt

Predation (x on y)





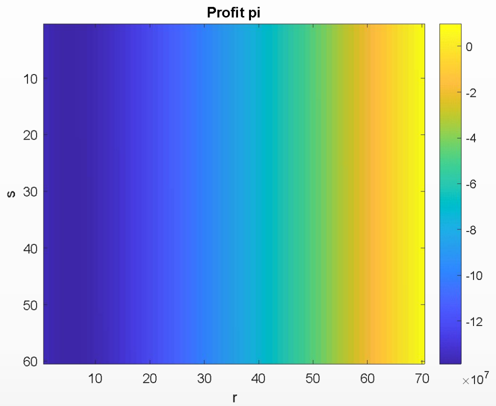


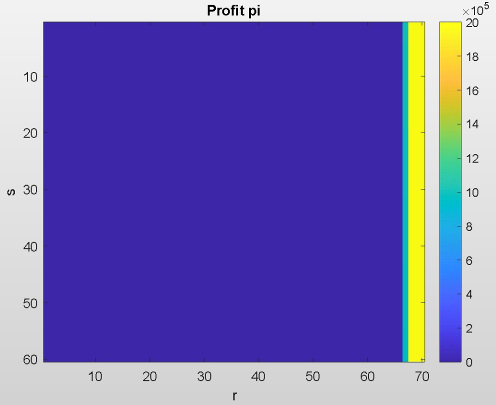
Predation

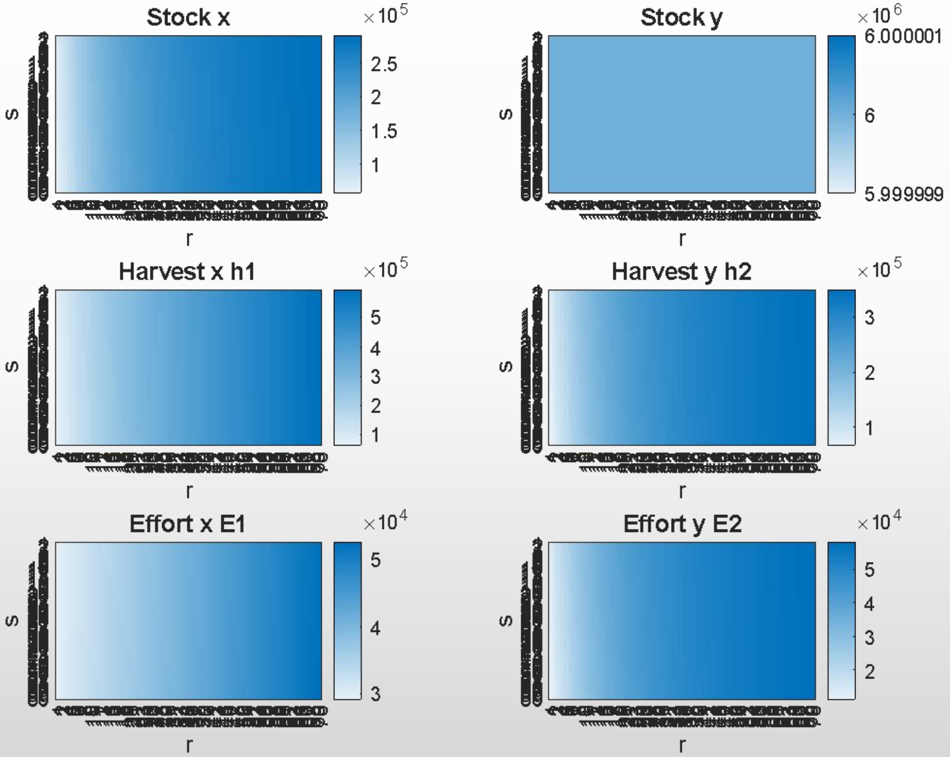
alpha = 1e-8; %interaction coefficient in F(x,y) = growth function of x

beta = -2e-8; %interaction coefficient in G(x,y)= growth function of y

Growth: r and s







Parameter (scaling) for the simulation

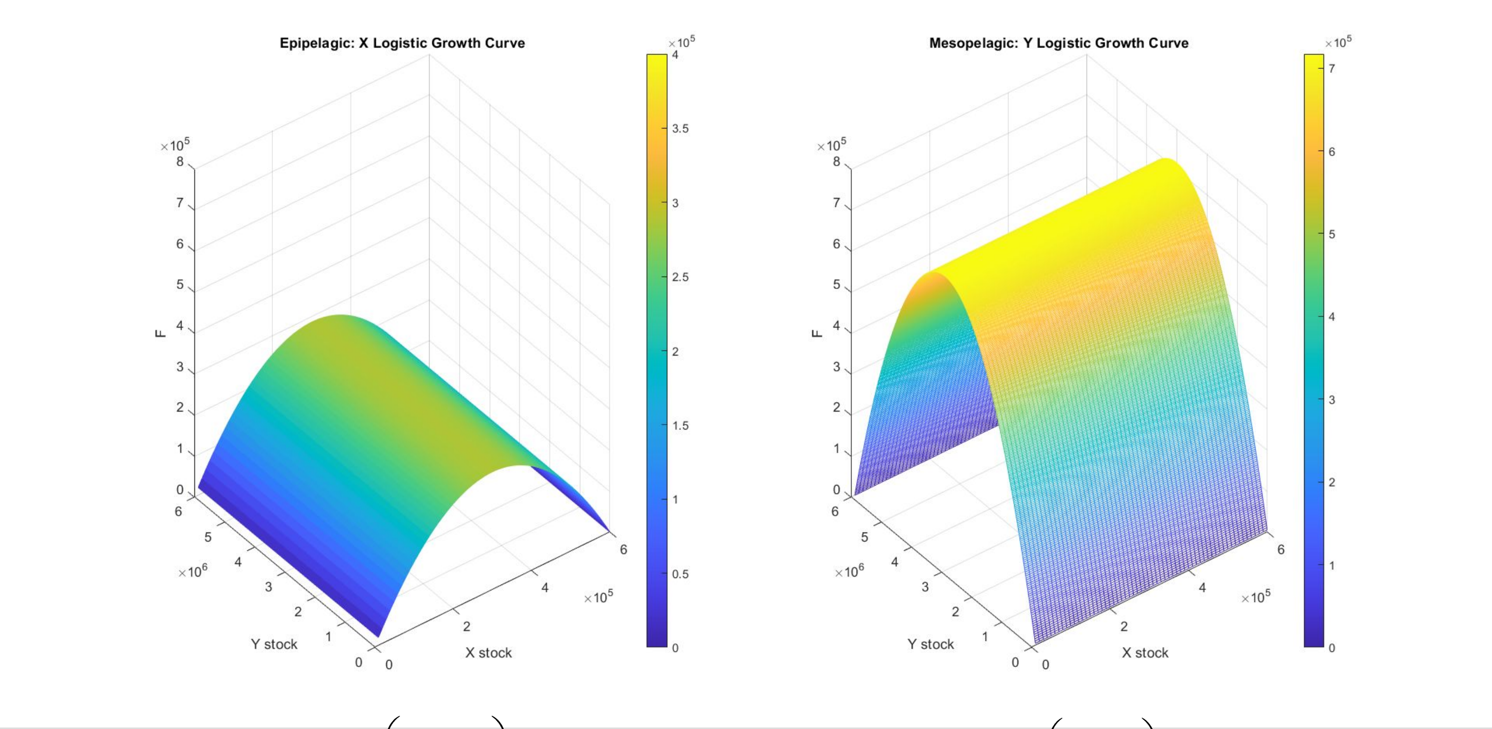
- Cost $c_1 < c_2$ double the cost
- Price $p_1 < p_2$ half the price
- Catchability $q_1 > q_2$ 40 orders of magnitude higher
- Carrying Capacity $K_1 < K_2$ 10 orders of magnitude higher
- Intrinsic Growth rate r1 > r2 4 orders of magnitude smaller

(Jin, & Hoagland, 1997, yellowfin tuna)

Seeking input

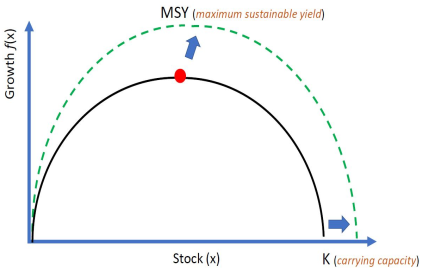
- Growth
  - r, K missing
  - population growth dynamics
- Catchability coefficient q
- Harvesting costs

Neutralism: α = 0, β = 0

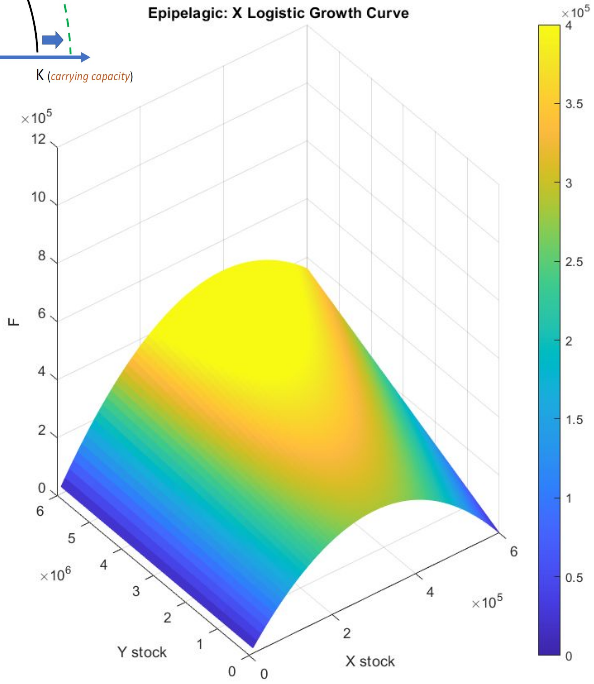


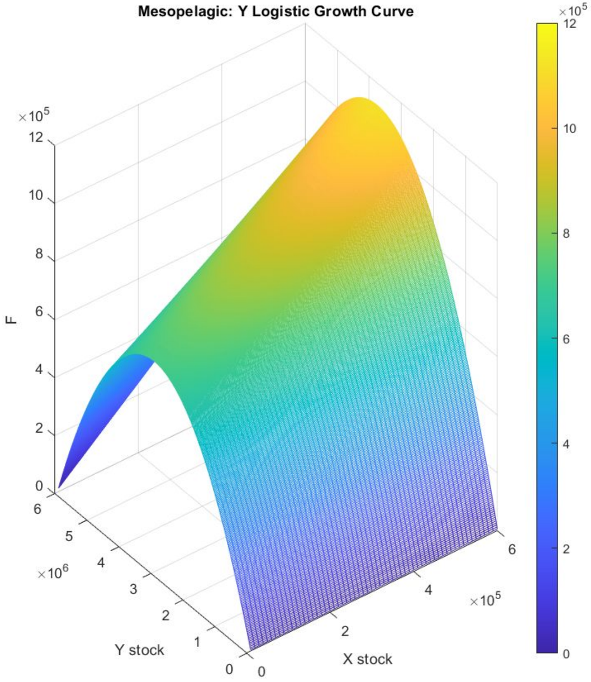
$$F(x,y) = rx\left(1-\frac{x}{K}\right)+axy$$

$$G(x,y) = sy\left(1-\frac{y}{L}\right)+\beta xy$$



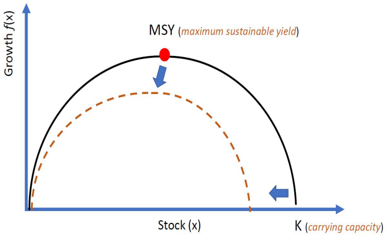
Mutualism: α > 0, β > 0



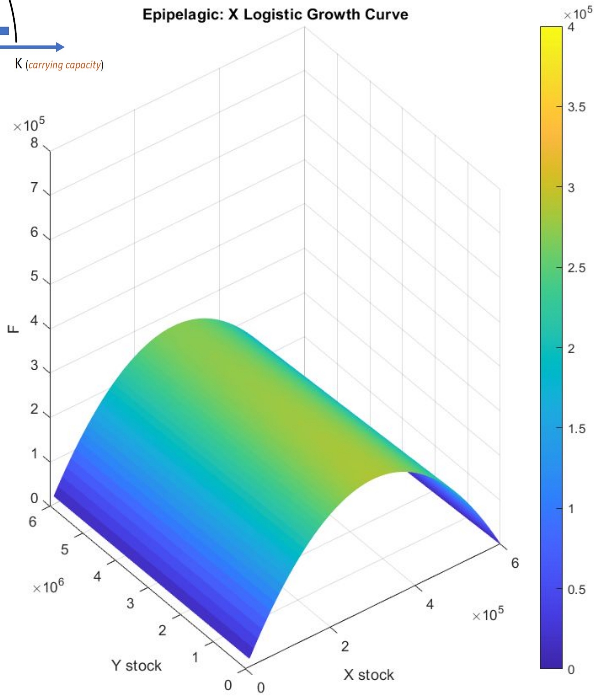


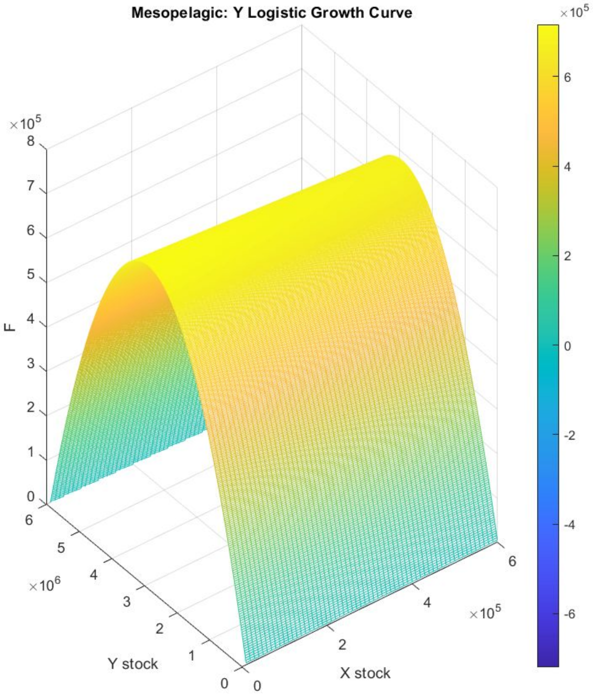
$$F(x,y) = rx\left(1 - \frac{x}{K}\right) + axy$$

$$G(x,y) = sy\left(1 - \frac{y}{L}\right) + \beta xy$$



Competition: $\alpha < 0, \beta < 0$





$$F(x,y) = rx\left(1 - \frac{x}{K}\right) + axy$$

$$G(x,y) = sy\left(1 - \frac{y}{L}\right) + \beta xy$$

Prey, Predation: α > 0, β < 0

$$F(x,y) = rx\left(1 - \frac{x}{K}\right) + \alpha xy \qquad G(x,y) = sy\left(1 - \frac{y}{L}\right) + \beta xy$$