Cooperative Management of Trans-boundary Fish Stocks: Implications for Tropical Tuna Management in the Pacific Island Region

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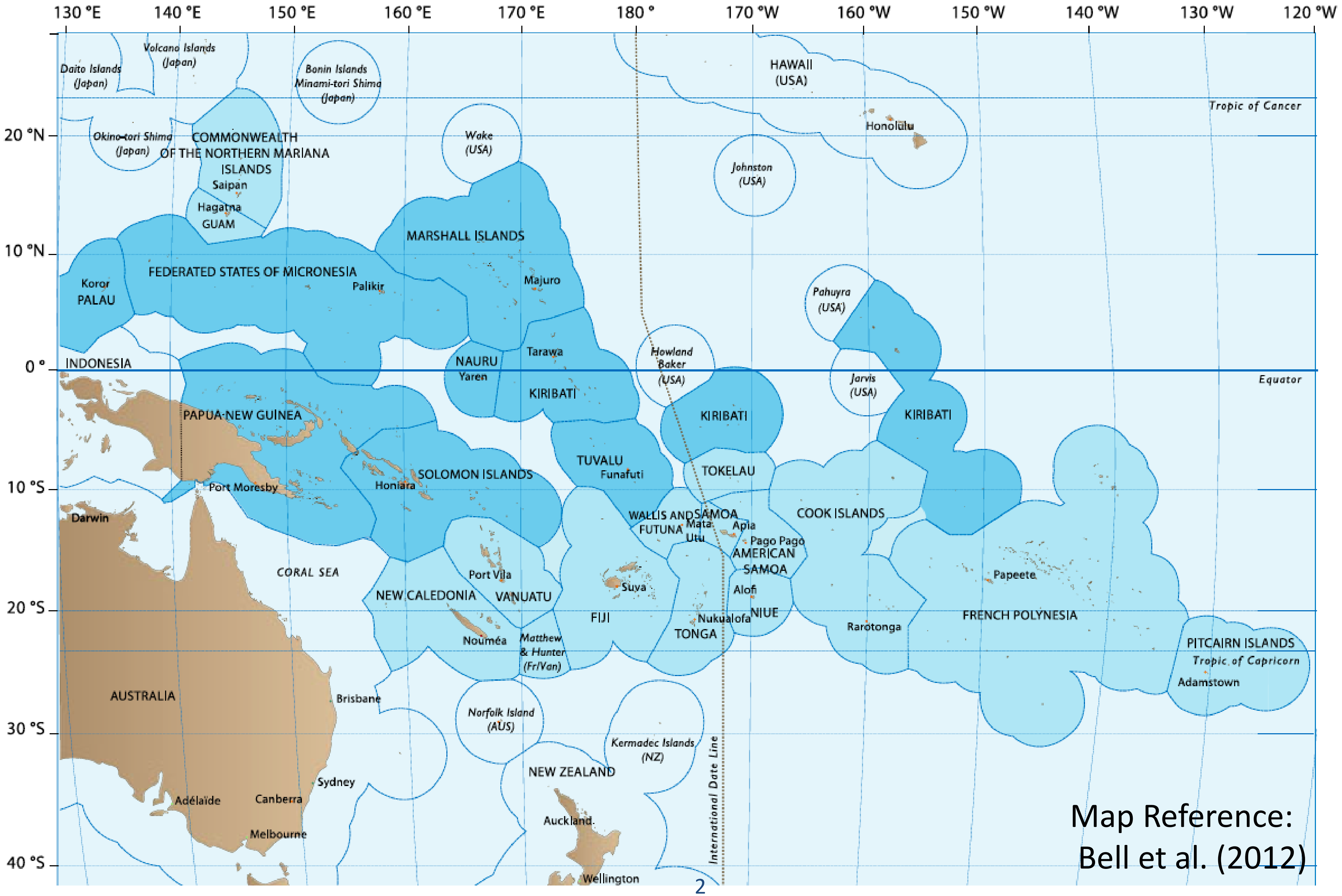
Western and Central Pacific



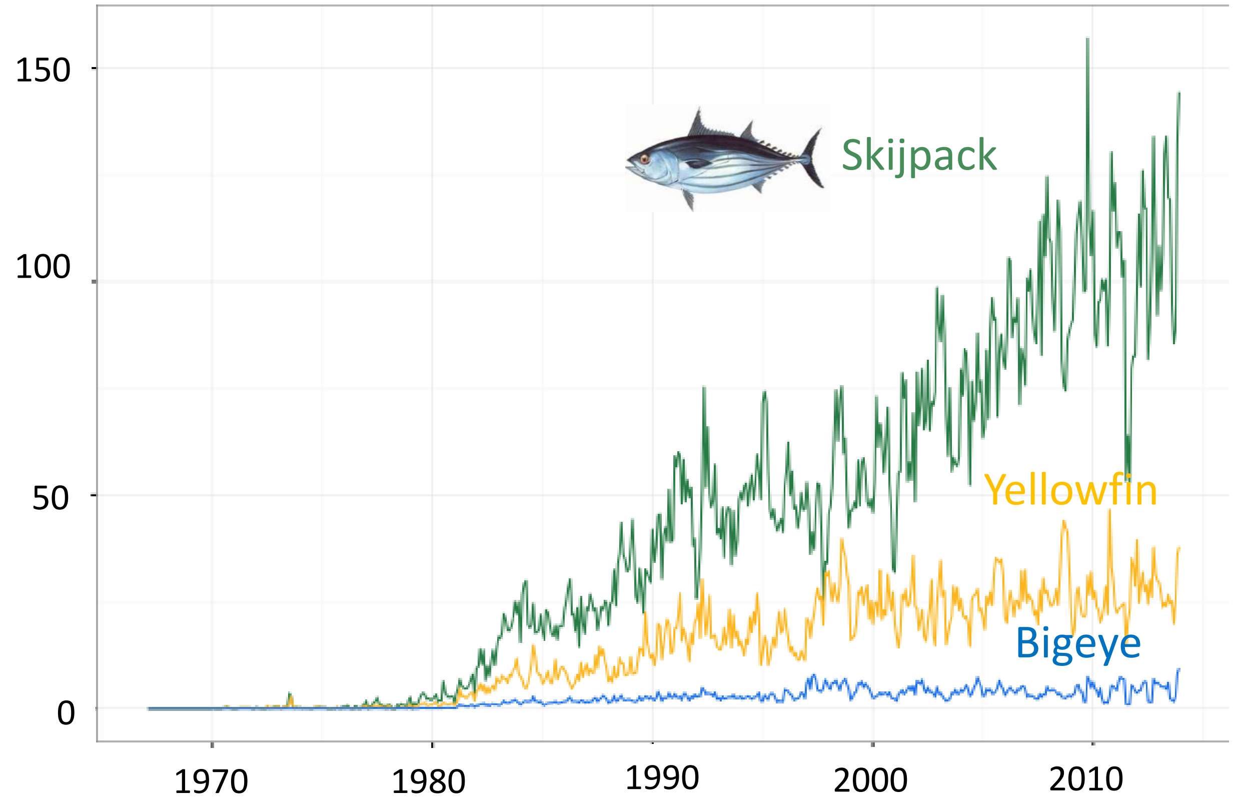
Map Reference: Bell et al. (2012)

Outline

- Motivation:
  - Pacific island countries have rich fisheries resources
    - Benefit from the resources through the sales of fishing licenses to distant water fishing vessels
  - Pacific island countries cooperate to manage their fisheries resources
  - The cooperative management face challenges:
    - EEZs are surrounded by the international waters
    - (Climate change alters fish migration and stock distribution)
- Objective:
  - Understand gains from cooperative management in relation to fish migration
- Method:
  - Dynamic bioeconomic model that takes fish migration and existence of international waters into account

Pacific Tropical Tuna Fishery Overview

Harvest by Purse Seine Vessels (Metric Ton)

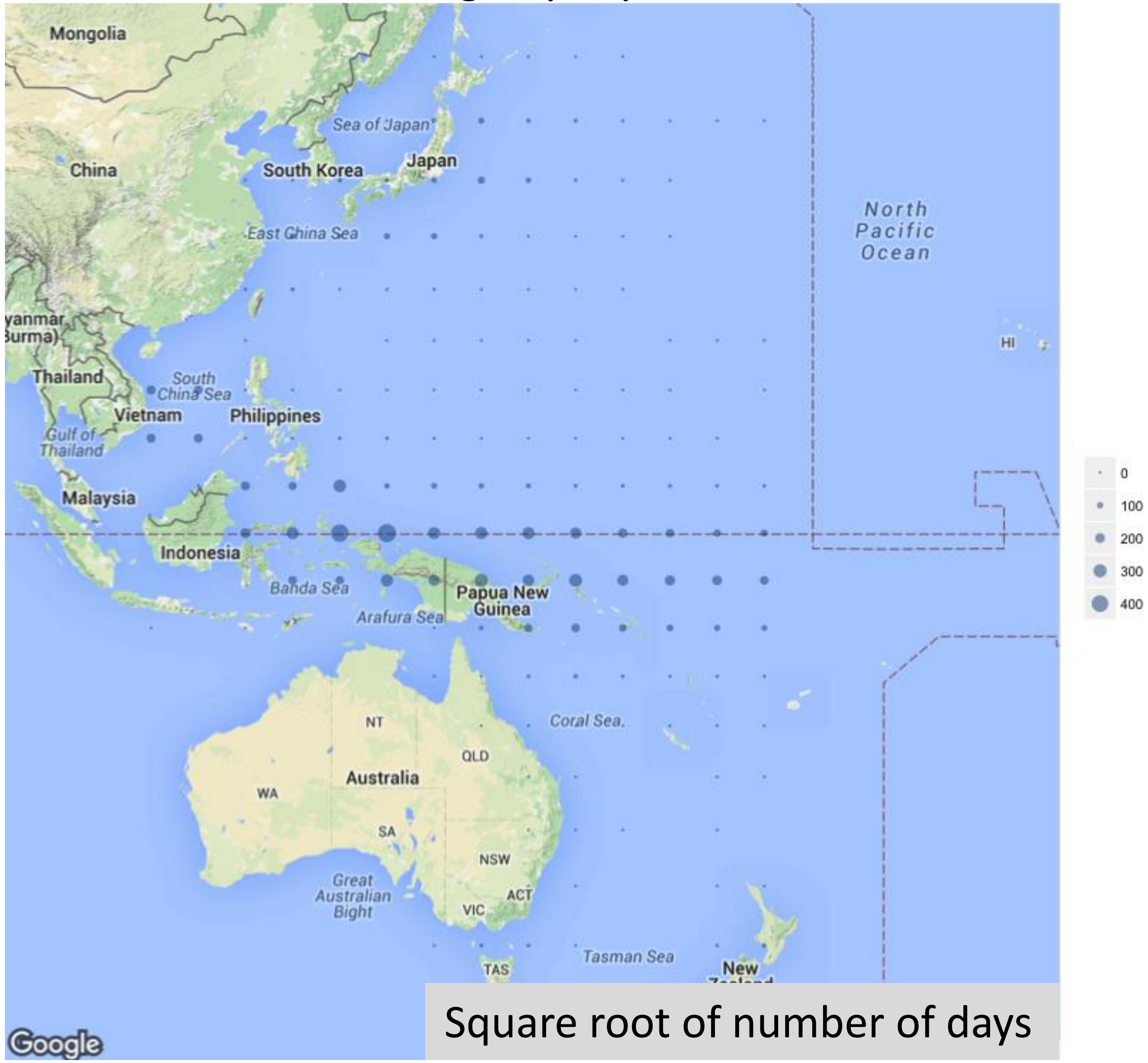


- Key players:
  - Coastal states: Western and Central Pacific Island States
  - Distant Water Fishing Nations: Japan, Korea, Taiwan, US, EU
- Target Species: Skipjack, Yellowfin, Albacore, Bigeye
- Gears: Purse seine, Longline, Pole and line
- Market: Canned tuna, Sashimi

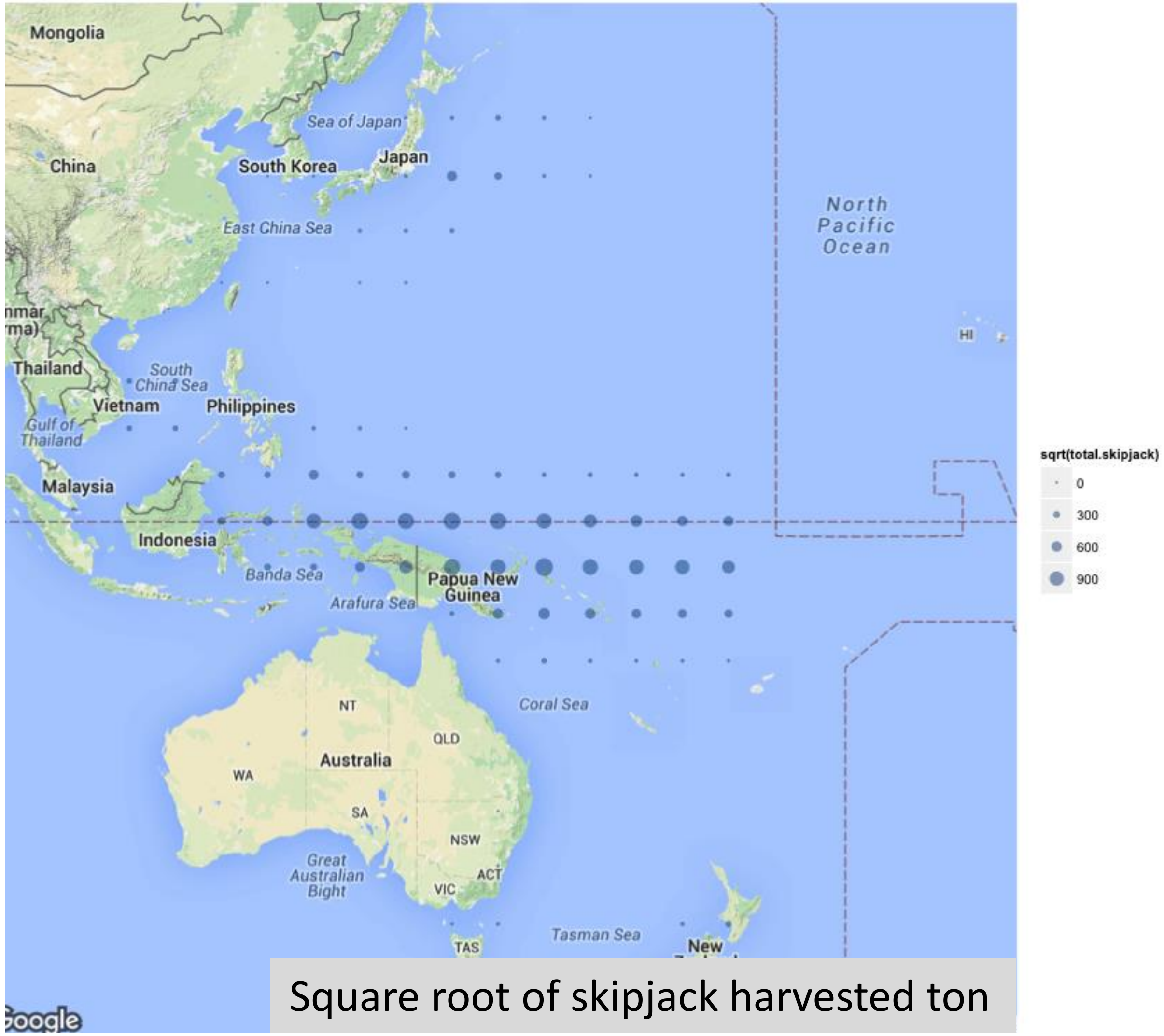
Image source: FAO

Location of the Fishing(1970-2013)

Total Efforts in Fishing Days by Purse Seine Vessels

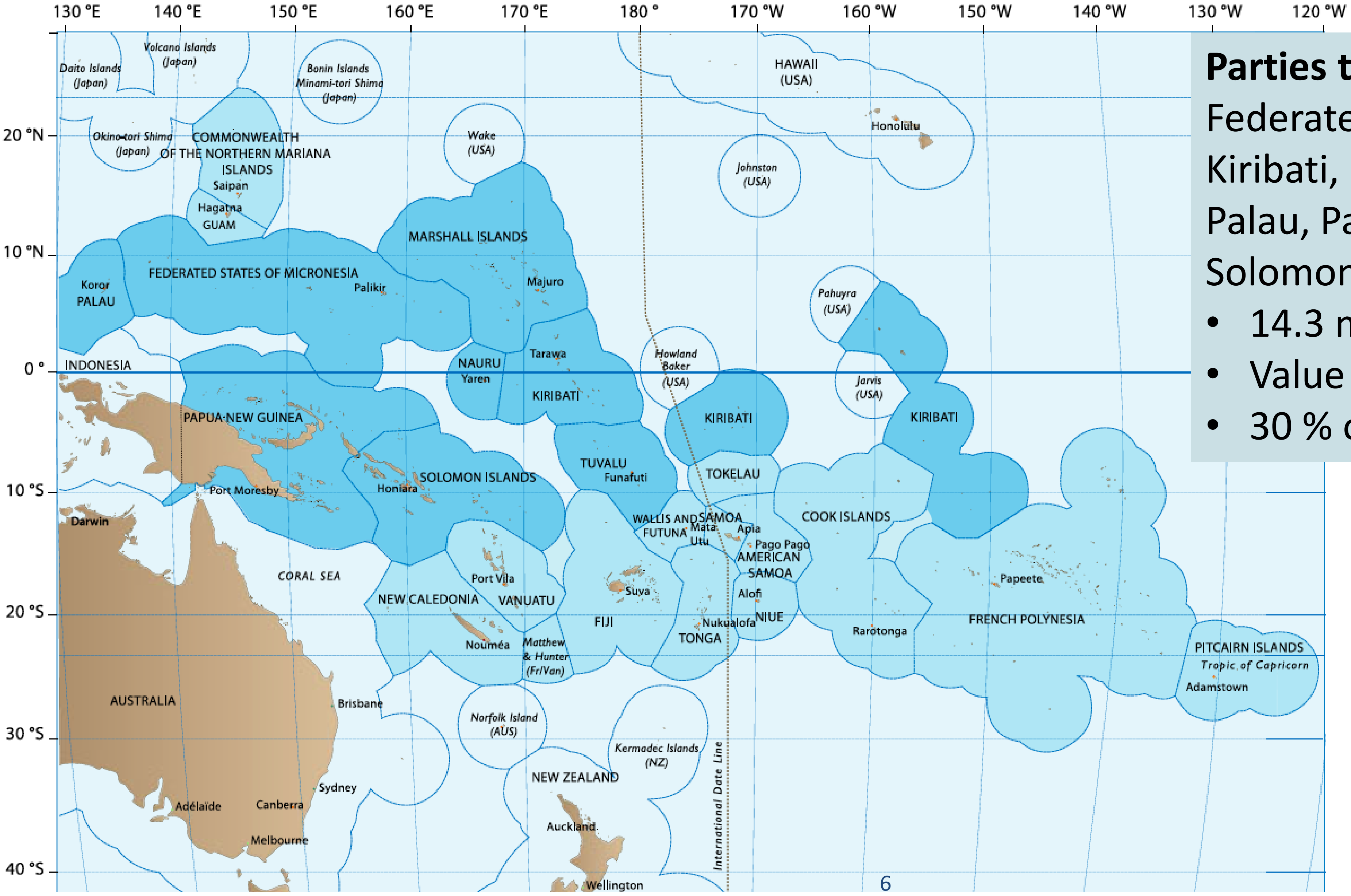


Total Catch of Skipjack by Purse Seine Vessels



Data Source: WCPFC

Cooperation Through the Nauru Agreement



Parties to the Nauru Agreement

Federated States of Micronesia, Kiribati, Marshall Islands, Nauru, Palau, Papua New Guinea, Solomon Islands, and Tuvalu

- 14.3 million sq. km
- Value over $2 billion per year
- 30 % of global tuna supply

Reference: The Pew Charitable Trust

Map source: Bell et al. (2012)

Previous Studies on Trans-boundary Fish Stocks (Models with Spatial Dynamics)

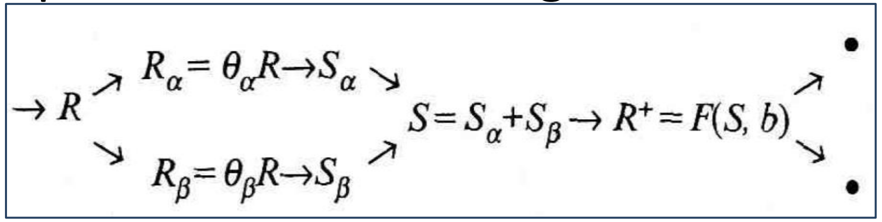
Shared stocks:

- Munro (1979): Nash cooperative game
- Levhari & Mirman (1980): Nash-Cournot duopolists

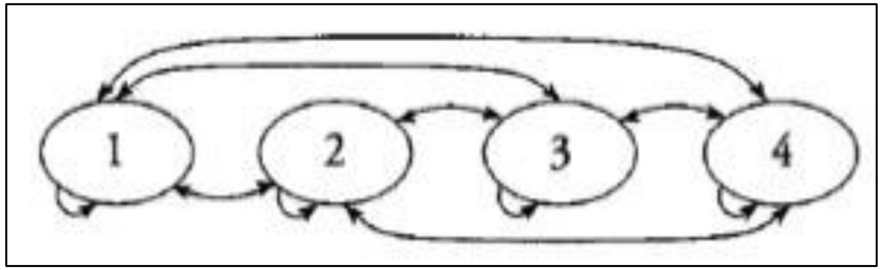
Migrating stocks:

- Golubtsov & McKelevy (2007)
  - Split-stream Harvesting
  - Application Ex: Mackerel (Hannesson (2013))
- Sanchirico & Wilen (1999); Costello & Polasky (2008); Smith et al. (2009) etc.
  - Patchy Environment
  - Application Example: MPAs

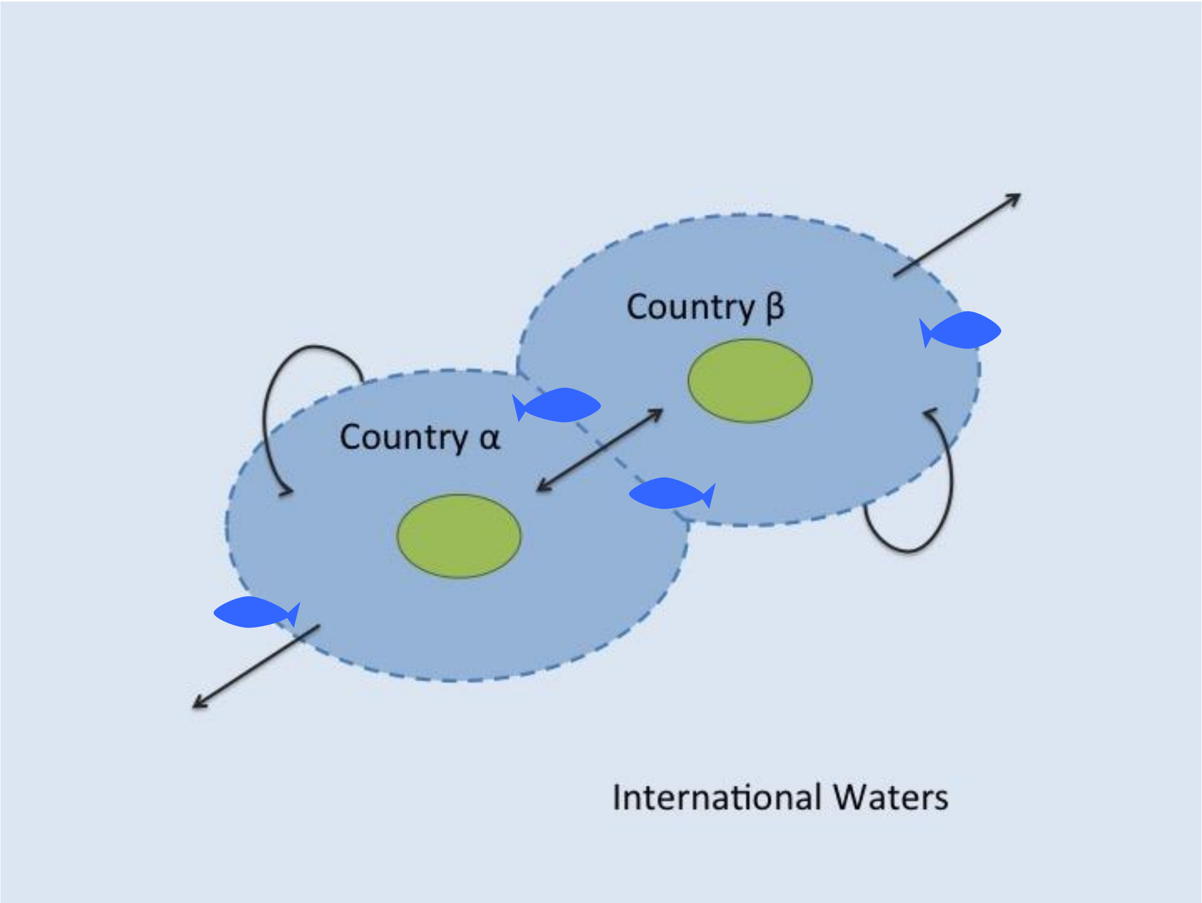
Split-stream Harvesting (Golubstov & McKelevy (2007))



Patchy Environment

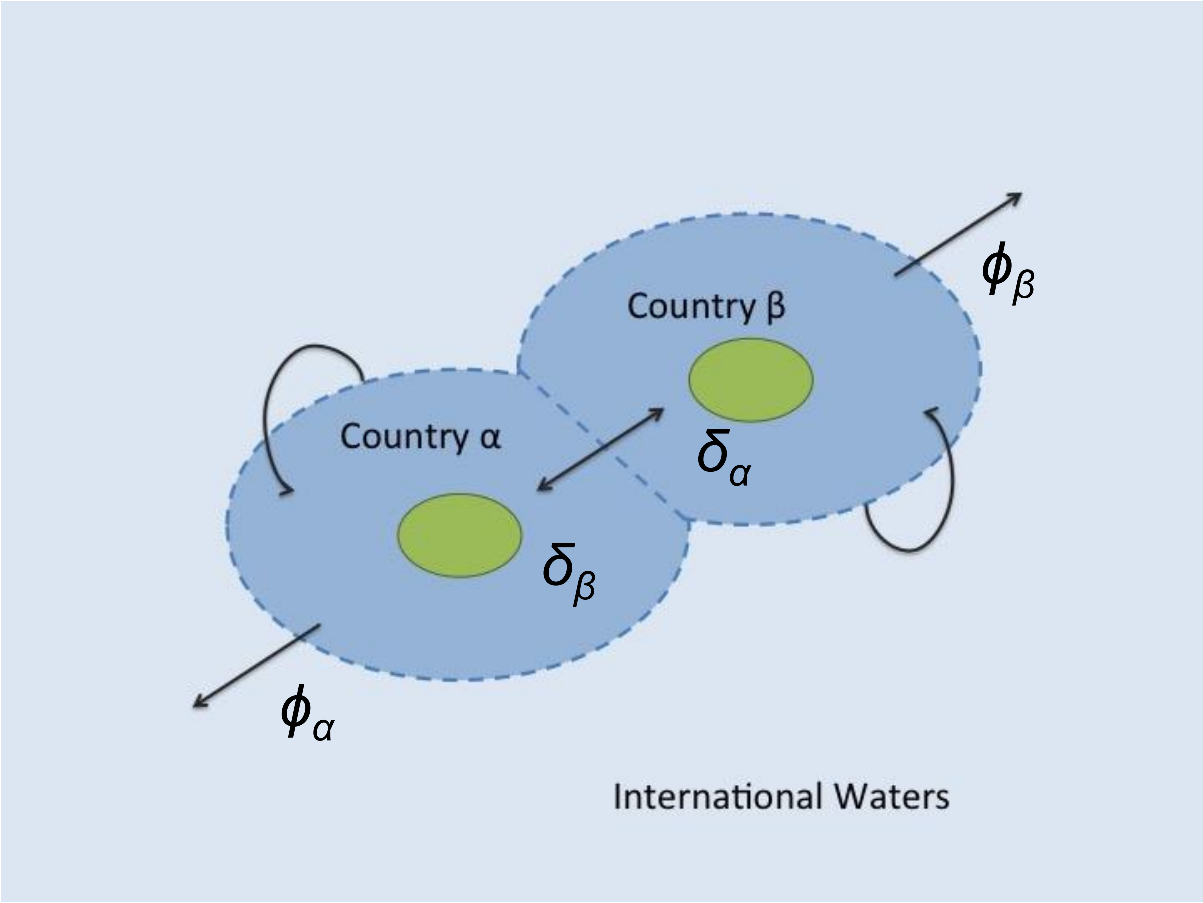


Model Framework for Pacific Tuna Management by the PIC



- Key Characteristics:
  - EEZs surrounded by international waters
  - Spawning is spread across the Pacific
  - Feeding migration
- Framework
  - 2 countries: α and β

Framework



$$\dot{S}_{\alpha,t} = F(S_{\alpha,t}) - x_{\alpha,t}$$
$$\dot{S}_{\beta,t} = F(S_{\beta,t}) - x_{\beta,t}$$

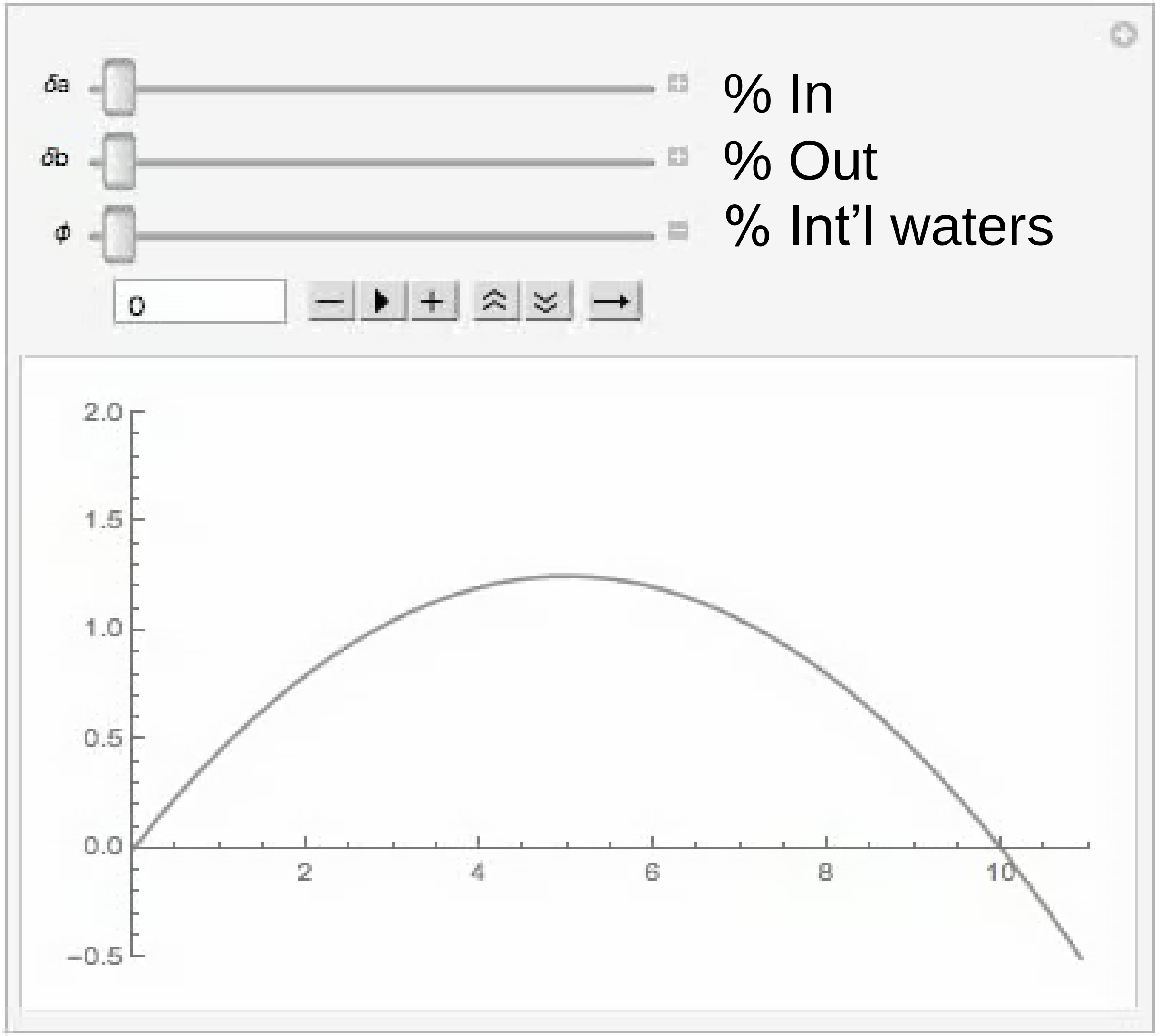
Growth - Harvest

% To neighbor's waters (outgoing)

% To international waters (outgoing)

% from neighbor's waters (incoming)

At the Steady State



$$\dot{S} = 0$$

$$x_{\beta,t} = F(S_{\beta,t}) - (\phi_\beta + \delta_\beta)S_{\beta,t} + \delta_\alpha \bar{S}_{\alpha,t}$$

Present Value of Net Benefit from Cooperative Management

Joint Maximization Problem

Total Revenue

Total Cost

$$\max_{x_{\alpha,t},x_{\beta,t}} \int_0^\infty e^{-\rho t}\left[\boxed{px_{\alpha,t} + px_{\beta,t}} \boxed{- c(S_{\alpha,t})x_{\alpha,t} - c(S_{\beta,t})x_{\beta,t}}\right]dt$$

subject to

$$\dot{S}_{\alpha,t} = F(S_{\alpha,t}) - x_{\alpha,t} - (\phi_\alpha + \delta_\alpha)S_{\alpha,t} + \delta_\beta S_{\beta,t}$$

$$\dot{S}_{\beta,t} = F(S_{\beta,t}) - x_{\beta,t} - (\phi_\beta + \delta_\beta)S_{\beta,t} + \delta_\alpha S_{\alpha,t}$$

S_0 given ← Initial stock

$x_{i,t} \in [0, x^{\max}]$ ← Upper bound

Steady State Conditions under Cooperative Management

Steady state stocks satisfy the conditions:

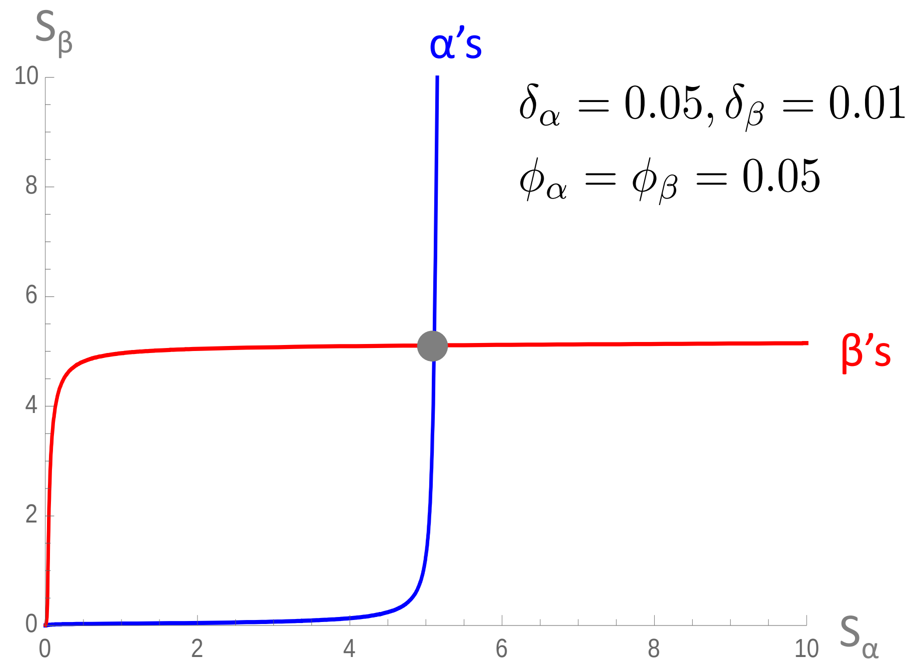
$$[\rho - F'(S_\alpha^*) + (\phi_\alpha + \delta_\alpha)][p - c(S_\alpha^*)] - \delta_\alpha[p - c(S_\beta^*)] + c'(S_\alpha^*)[F(S_\alpha^*) - (\phi_\alpha + \delta_\alpha)S_\alpha^* + \delta_\beta S_\beta^*] = 0$$

$$[\rho - F'(S_\beta^*) + (\phi_\beta + \delta_\beta)][p - c(S_\beta^*)] - \delta_\beta[p - c(S_\alpha^*)] + c'(S_\beta^*)[F(S_\beta^*) - (\phi_\alpha + \delta_\beta)S_\beta^* + \delta_\alpha S_\alpha^*] = 0$$

Once the steady state stocks are determined, we can find the harvests from:

$$x_\alpha^* = F(S_\alpha^*) - (\phi_\alpha + \delta_\alpha)S_\alpha^* + \delta_\beta S_\beta$$

$$x_\beta^* = F(S_\beta^*) - (\phi_\beta + \delta_\beta)S_\beta^* + \delta_\alpha S_\alpha$$



Present Value of Net Benefit from Independent Management

α's Maximization Problem

$$\max_{x_{\alpha,t}} \int_0^\infty e^{-\rho t}[p x_{\alpha,t} - c(S_{\alpha,t}) x_{\alpha,t}]dt$$

subject to

$$\dot{S}_{\alpha,t} = F(S_{\alpha,t}) - x_{\alpha,t} - (\phi_\alpha + \delta_\alpha) S_{\alpha,t} + \delta_\beta \bar{S}_{\beta,t}$$

S_0 given ← Initial stock

$x_{i,t} \in [0, x^{\max}]$ ← Upper bound

β's Maximization Problem

$$\max_{x_{\beta,t}} \int_0^\infty e^{-\rho t}[p x_{\beta,t} - c(S_{\beta,t}) x_{\beta,t}]dt$$

subject to

$$\dot{S}_{\beta,t} = F(S_{\beta,t}) - x_{\beta,t} - (\phi_\beta + \delta_\beta) S_{\beta,t} + \delta_\alpha \bar{S}_{\alpha,t}$$

S_0 given ← Initial stock

$x_{i,t} \in [0, x^{\max}]$ ← Upper bound

Steady State Conditions under Independent Management

α's conditions

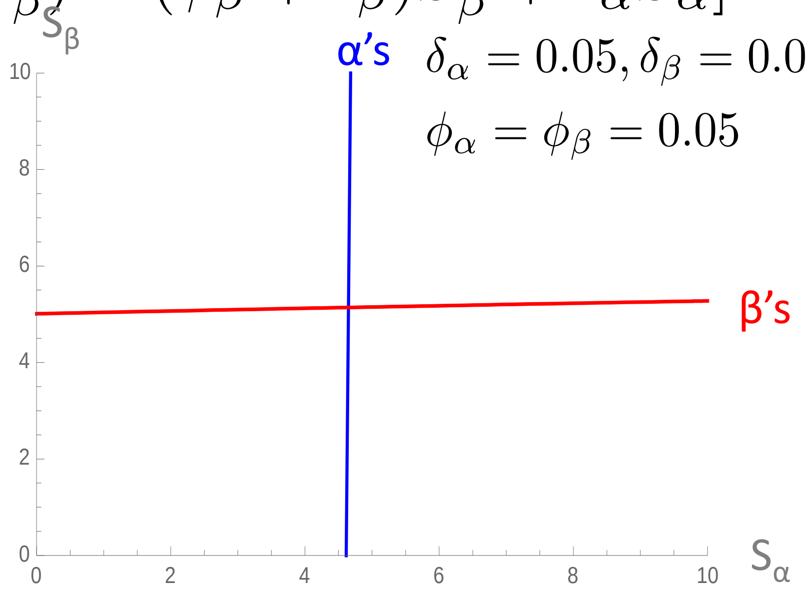
$$[\rho - F'(S^I_\alpha) + (\phi_\alpha + \delta_\alpha)][p - c(S^I_\alpha)] + c'(S^I_\alpha)[F(S^I_\alpha) - (\phi_\alpha + \delta_\alpha)S^I_\alpha + \delta_\beta \bar{S}_\beta] = 0$$

$$x^I_\alpha = F(S^I_\alpha) - (\phi_\alpha + \delta_\alpha)S^I_\alpha + \delta_\beta \bar{S}_\beta$$

β's conditions

$$[\rho - F'(S^I_\beta) + (\phi_\beta + \delta_\beta)][p - c(S^I_\beta)] + c'(S_\beta)[F(S^I_\beta) - (\phi_\beta + \delta_\beta)S^I_\beta + \delta_\alpha \bar{S}_\alpha] = 0$$

$$x^I_\beta = F(S^I_\beta) - (\phi_\beta + \delta_\beta)S^I_\beta + \delta_\alpha \bar{S}_\alpha$$



$\delta_\alpha = 0.05, \delta_\beta = 0.01$

$\phi_\alpha = \phi_\beta = 0.05$

Cooperative Management vs. Independent Management

Cooperative Management

$$[\rho - F'(S_\alpha^C) + (\phi_\alpha + \delta_\alpha)][p - c(S_\alpha^C)] - \delta_\alpha[p - c(S_\beta^C)] + c'(S_\alpha^C)[F(S_\alpha^C) - (\phi_\alpha + \delta_\alpha)S_\alpha^C + \delta_\beta S_\beta^C] = 0$$

$$[\rho - F'(S_\beta^C) + (\phi_\beta + \delta_\beta)][p - c(S_\beta^C)] - \delta_\beta[p - c(S_\alpha^C)] + c'(S_\beta^C)[F(S_\beta^C) - (\phi_\beta + \delta_\beta)S_\beta^C + \delta_\alpha S_\alpha^C] = 0$$

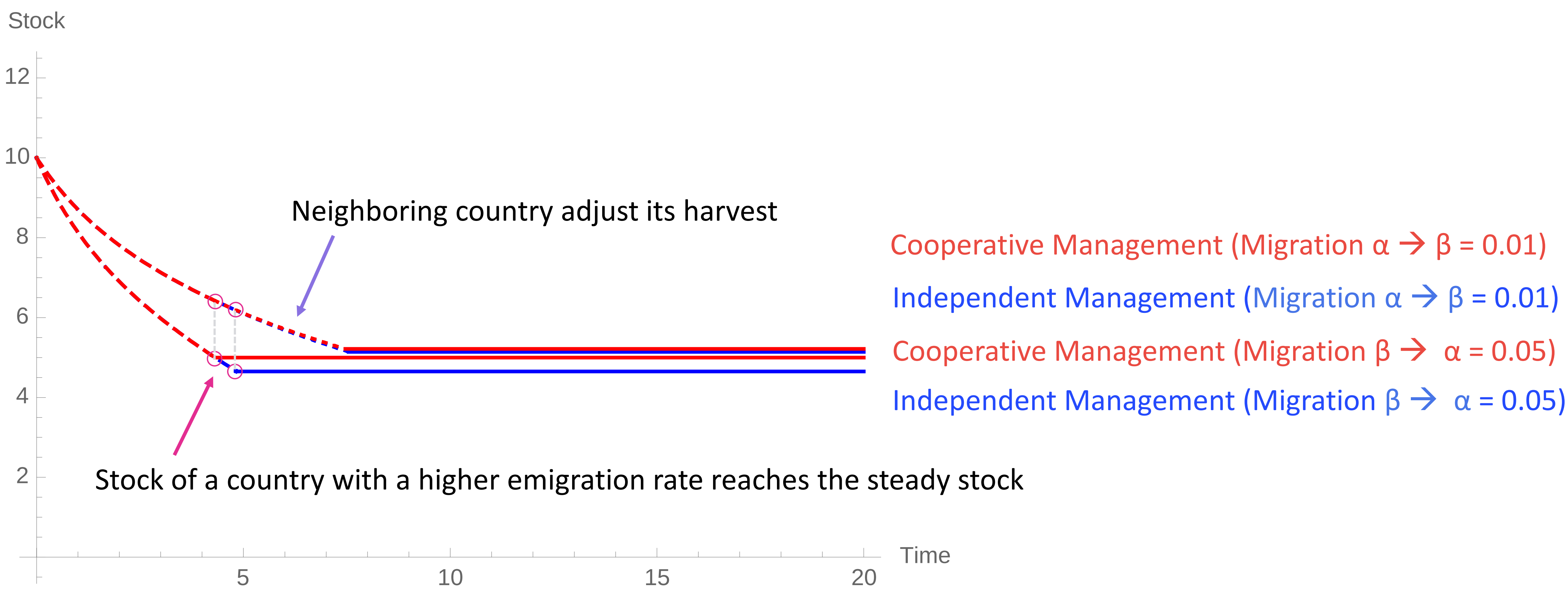
(% moving from i's EEZ to j's EEZ) × (j's shadow price)

Independent Management

$$[\rho - F'(S_\alpha^I) + (\phi_\alpha + \delta_\alpha)][p - c(S_\alpha^I)] + c'(S_\alpha^I)[F(S_\alpha^I) - (\phi_\alpha + \delta_\alpha)S_\alpha^I + \delta_\beta \bar{S}_\beta] = 0$$

$$[\rho - F'(S_\beta^I) + (\phi_\beta + \delta_\beta)][p - c(S_\beta^I)] + c'(S_\beta)[F(S_\beta^I) - (\phi_\beta + \delta_\beta)S_\beta^I + \delta_\alpha \bar{S}_\alpha] = 0$$

Stock Dynamics (S_0 = Carrying Capacity, Equal Leakage Rate)



Main point

- Cooperative management yields higher steady state stock level
- A steady stock level is higher for the country with lower emigration rate
- A country with a higher emigration rate reaches steady state first

Pacific Island Countries Sell Licenses to Distant Water Vessels

- Distant water fishing vessel's profit maximization problem

$$\max_{x_{i,j,t}} \Pi_{i,j} = px_{i,j,t} - c(S_{i,t})x_{i,j,t} - \eta_i d_{i,j}.$$

- For simplicity, suppose that a catch is linear in number of fishing days, such that

$$x_{i,j,t} = \nu d_{i,j,t}$$

- Distant water fishing vessel maximizes its profit by choosing how many days to operate

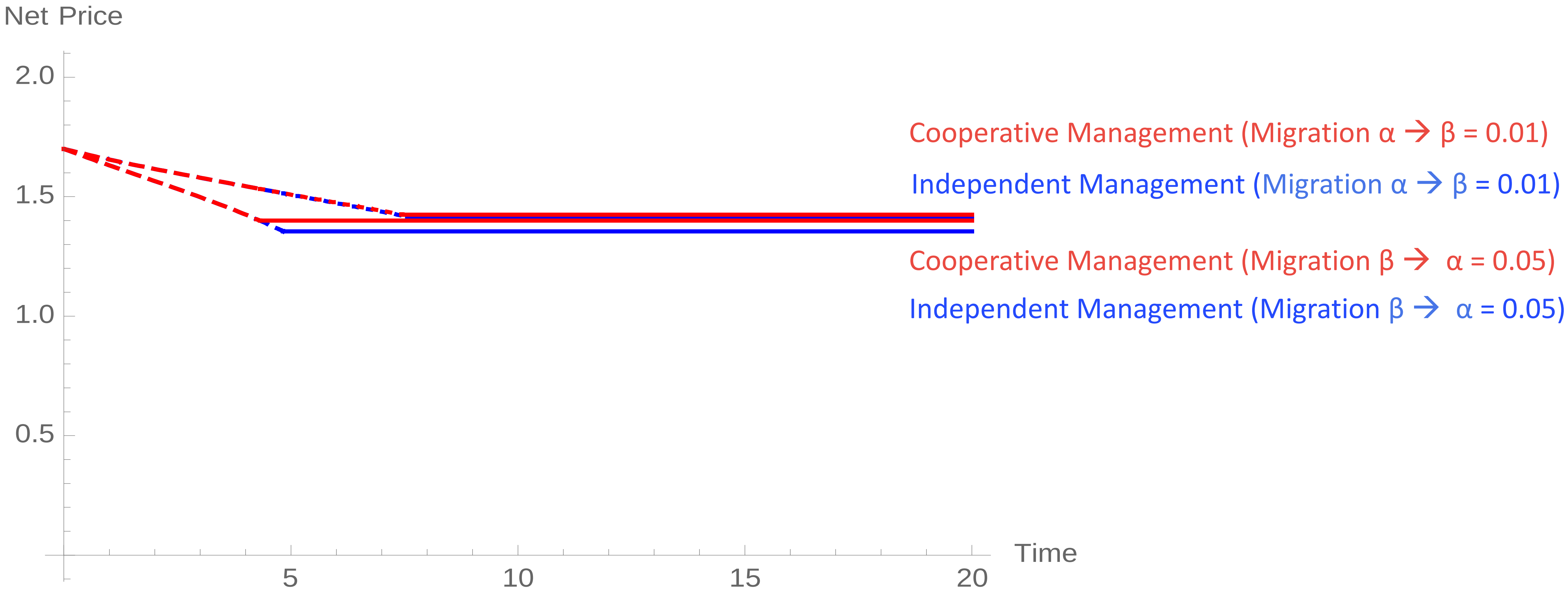
$$\max_{d_{i,j}} \Pi_{i,j} = p\nu d_{i,j} - c(S_i)\nu d_{i,j} - \eta_i d_{i,j}.$$

- First order condition yields

$$\eta_i = \nu(p - c(S_i))$$

Optimal license fee is determined by the product of daily harvest and the net price

Net Price Dynamics (S_0 = Carrying Capacity, Equal Leakage Rate)

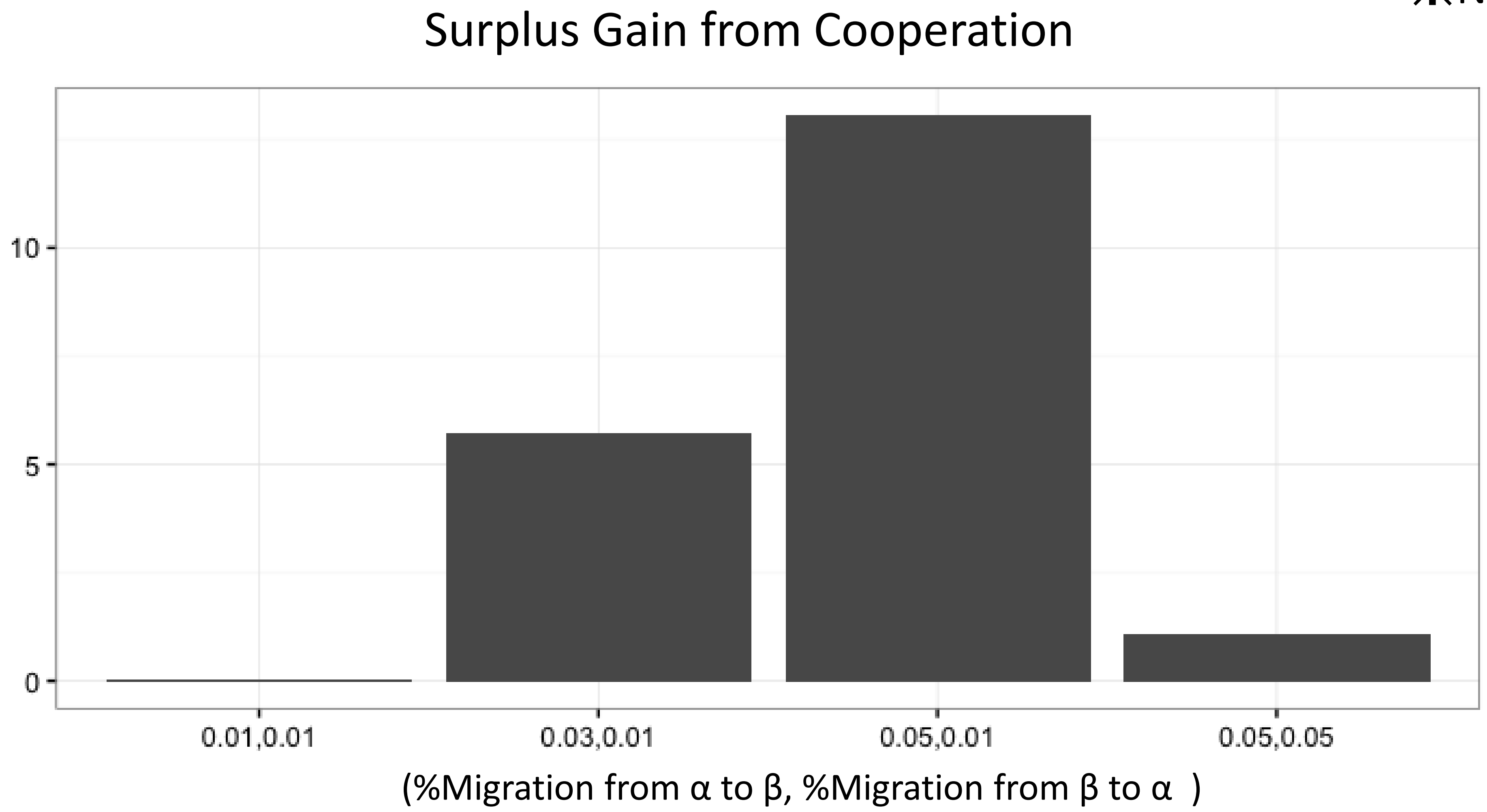


Main point

- Cooperative management yields higher steady state net price
  → Present value of net benefits higher under cooperation
- There is a relationship between migration parameters and net benefits

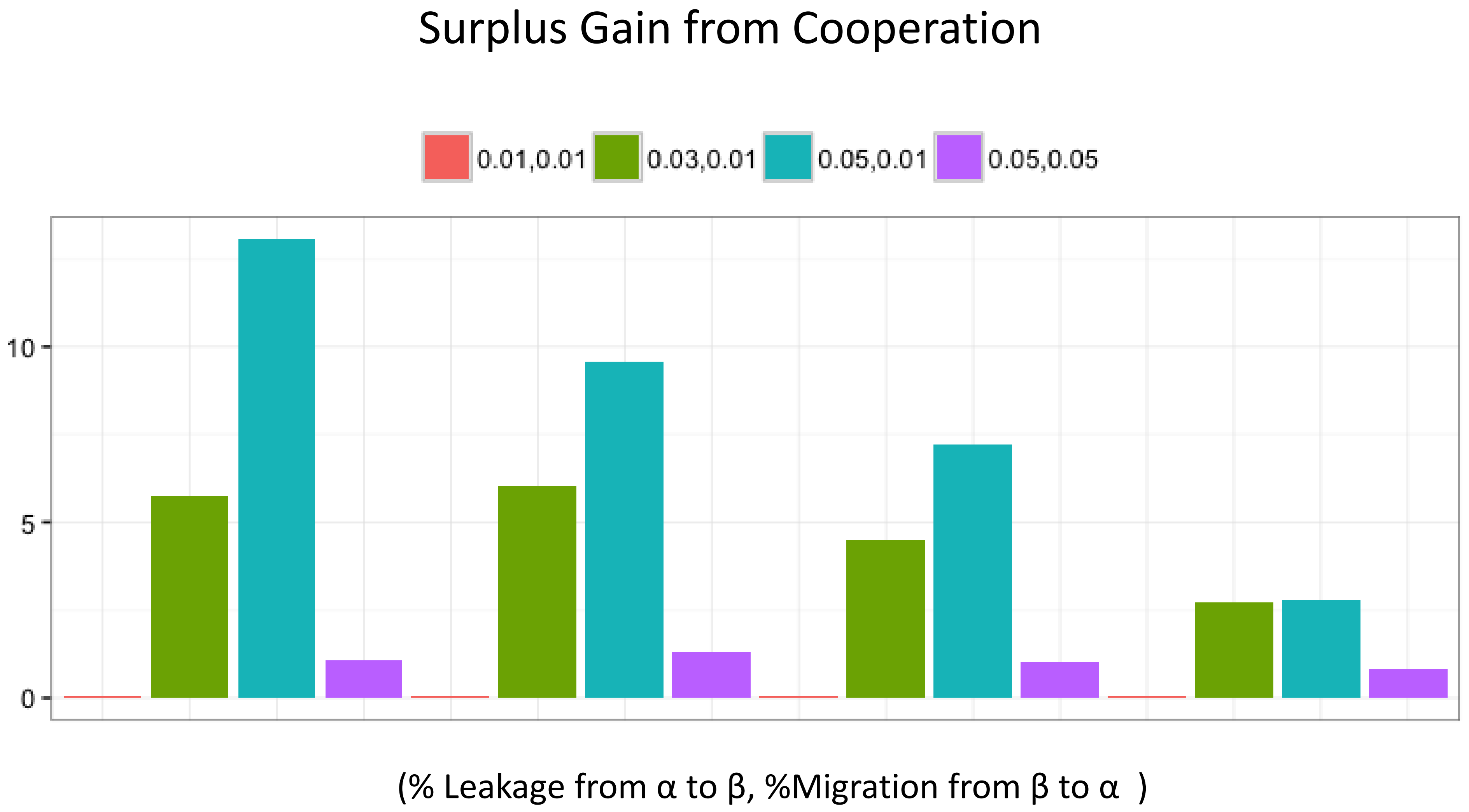
Migration between the Two Countries

※No Leakage



Cooperation benefit increases with an increase in net migration

Migration to International Waters



Cooperation benefits decreases with an increase in migration to international waters

So What? Why Should We Care?

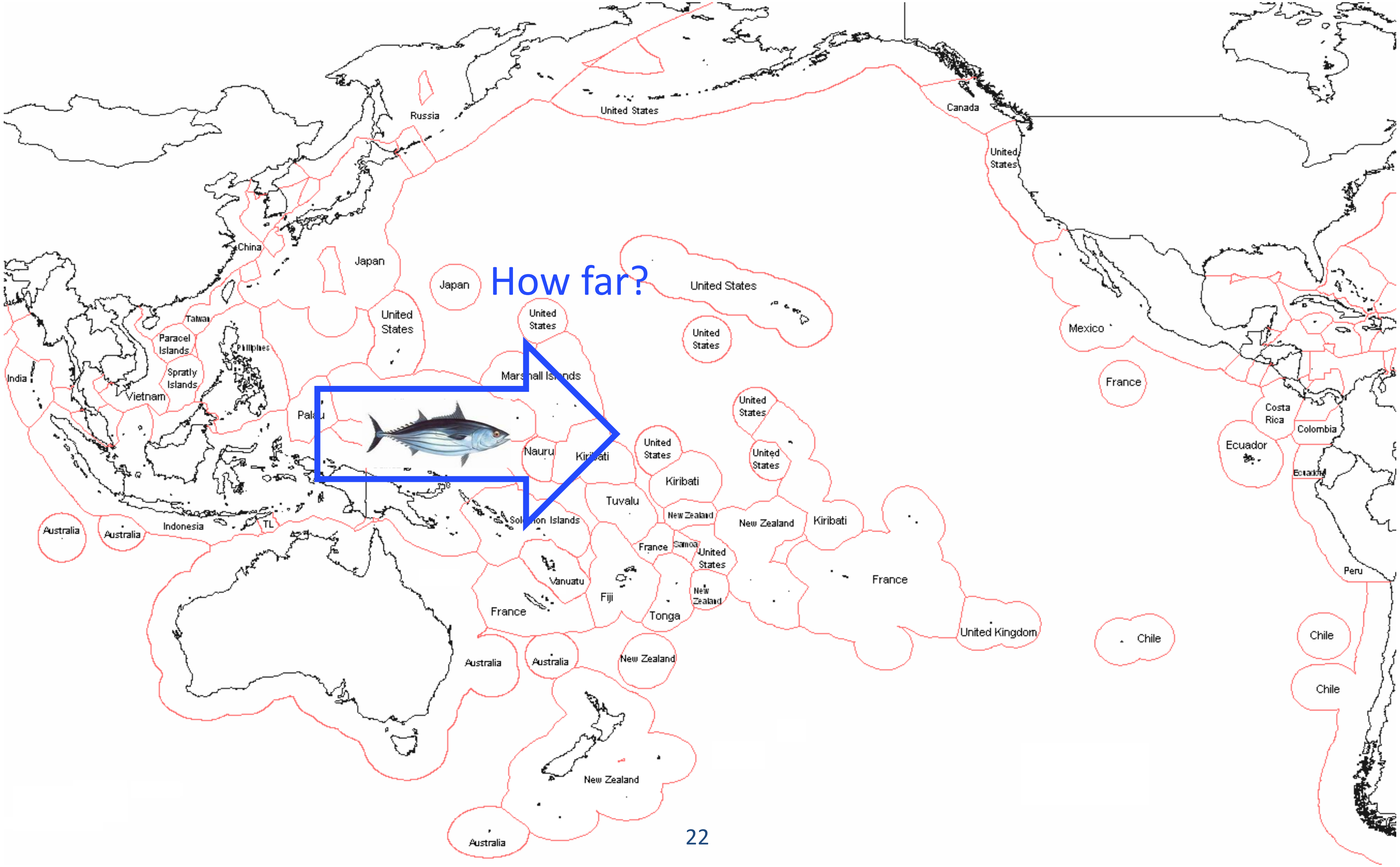
Predicted Change in Tuna Stock due to Climate Change

	2035	2050	2100
FSM	+14	+5	-16
Marshall Islands	+24	+24	+10
Nauru	+25	+20	-1
Palau	+10	+2	-27
Papua New Guinea	+3	-11	-30
Solomon Islands	+3	-5	-15
Kiribati	+37	+43	+24
Tuvalu	+37	+41	+25

Lehodey et al. (2011) cited in Bell et al. (2012) Table 1, Only PNA information shown here

East-ward Shift of Stock Predicted by Climate Change

Eastward shift of the stock is predicted (Ex. Lehodey 2011)



Conclusion

- A model of cooperative management
  - Key characteristics: International waters, distributed spawning, feeding migration
- Objective:
  - Understand gains from cooperative management in relation to fish migration
- Main findings
  - Cooperation benefit increases with an increase in net migration
  - Cooperation benefits decreases with an increase in migration to international waters
- Way forward
  - Countries cooperate if the gains from cooperation surpasses the costs of cooperation
  - More detailed simulation with spatial data

THANK YOU

Acknowledgement

I acknowledge the funding support by the Nippon Foundation on the University of Tokyo's Ocean Alliance project titled "Science on Consensus Building Methods for Ocean Use."

Allocation of the Surplus

Nash bargaining rule

$$\max_{\pi_\alpha, \pi_\beta} \quad (\pi_\alpha - \pi_\alpha^I)^\sigma (\pi_\beta - \pi_\beta^I)^{1-\sigma}$$

$$\text{subject to} \quad \pi_\alpha + \pi_\beta = \bar{\pi}$$

Benefits are shared 50:50 if the two countries have the equal negotiation power

Proportionate rule

$$(NB)_i^{Coop} - (NB)_i^{Ind}$$

If equal migration rates, benefits are shared 50:50

A country with the higher out-migration rate gains more

Total Efforts in Number of Fishing Days